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Test Results From a Comparative Evaluation of a Condensation Nuclei Fire Detector

Richard W. Bricker

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Test Results From a Comparative Evaluation of a Condensation Nuclei Fire Detector

Richard W. Bricker

Webb, Murray and Associates, Inc.
Houston, Texas

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TEST RESULTS FROM A COMPARATIVE EVALUATION OF A
CONDENSATION NUCLEI FIRE DETECTOR

ABSTRACT

A series of 138 tests was conducted to compare the fire/smoke alarm response of a Condensation Nuclei Fire Detector (CNFD) with photoelectric and ionization detectors.

Tests were conducted in a former control room 8.5 m (28 ft) by 8.9 m (29 ft 2 in) with a 2.7 m (9 ft) ceiling. The room had air supplied from above the ceiling and under the floor with return air exiting from ceiling grills. The environment was varied from 278 to 305 K (40 to 90 °F) and relative humidities from 8 to 65 percent. Four detection zones were located in the room. Each zone contained a sampling head for the CNFD, a photoelectric detector, and an ionization detector so that each detector system had four opportunities to alarm during tests. The particle level in the test room was also monitored during tests with a condensation nuclei particle counter.

The CNFD responded to 90 percent of exposures to smoldering plastic and 84 percent of exposures to visible fire. The photoelectric response was 43 and 12.5 percent respectively for the same conditions. The ionization response was 9 and 48 percent respectively.

INTRODUCTION

Currently installed smoke detectors in computer rooms and other high airflow areas are usually based on ionization chamber or photo-cell techniques and may not provide warning of a developing fire early enough to protect high-cost equipment. The lack of confidence in these systems is based on test experience in actual installations and appears to result from the dilution caused by high airflows. Also, the necessary electronics for providing alarm signals is an inherent part of each passive detector, and the detector is dependent on convection and airflow patterns to provide samples to the detector. This tends to make the installation complex and expensive, if a large number of detectors are used. When these systems are adjusted to provide an increased sensitivity to compensate for dilution effects, unacceptable false alarms may occur.

A Condensation Nuclei Fire Detector (CNFD) based on the condensation of nuclei in a cloud chamber has been developed by industry and appears to eliminate some of the deficiencies encountered in other systems. This is accomplished by having one set of electronics detect and provide the alarm function for up to 40 sample heads actively collecting samples that are returned to the central detection system.

Of even greater significance in detection performance of the CNFD is the condensation of nuclei in a cloud chamber which multiplies each particle size many times making this technique capable of measuring extremely small particles (sub-micrometer size) and, therefore, of detecting an incipient fire earlier than currently used systems without causing false alarms.

Although the CNFD has passed Underwriter Laboratories (UL) Test 268 which pertains to detection performance, reliability predictions, endurance cycling, and many other important parameters, UL tests do not include other significant conditions such as smoldering plastics, various airflows, and higher- and lower-than-normal temperatures and humidities. A literature search and discussions with experts in the field of smoke detector testing indicated that specific testing of this type had not been previously conducted. The Johnson Space Center Safety Division proposed a test program to NASA Headquarters that was approved to evaluate nondestructively the detection performance of the CNFD. Tests were conducted in a typical JSC computer/control room at ambient and other environmental conditions such as various airflows and in higher- and lower-than-normal temperatures and humidities. The CNFD was evaluated using typical computer room products of combustion sources and its performance compared with both photoelectric and ionization detectors.

The purpose of this test report is to present the techniques, results, and conclusions resulting from 138 tests.

TEST PROGRAM

OBJECTIVES

The primary objective of this program was to determine if the CNFD is superior to currently used smoke detectors regarding alarm response, false alarm susceptibility, and maintenance requirements.

Specific objectives in meeting this goal and for providing a comprehensive evaluation of the CNFD were as follows:

1. Expose the CNFD to smoke sources resulting from an over-heated electrical cable and burning paper and compare its performance with currently used ionization and photoelectric detectors.
2. Determine the effects of higher- and lower-than-normal temperature and humidity on detection performance.
3. Evaluate detector response versus the effects of air velocities and various detector head directional geometries.
4. Evaluate the effects of background particle levels on detector response performance in both occupied and unoccupied areas.
5. Determine from test experience if maintenance requirements in addition to those recommended by the manufacturer are required.
6. As a result of the evaluation of test results, identify any potential design changes which could improve performance. Make recommendations concerning any identified problem areas for future study.

HARDWARE AND DATA ACQUISITION

Three different types of fire detection systems were involved in the test program. The primary system under evaluation was a Condensation Nuclei Fire Detector and for direct comparison purposes, both photoelectric and ionization detectors were utilized.

Condensation Nuclei Fire Detector (CNFD)

Manufacturer and Model - Environment One Corporation,
Schnectady, New York, Model Nr. E-1012F - 001 G2

The main elements of the CNFD are the following:

1. Air Sampling System
2. Measuring System
3. Alarm Circuitry

The function of the air sampling system is to provide samples of air from several locations in each of four zones to the measuring system.

The measuring system interrogates the air sample for combustion products. If the level of combustion products exceeds preset levels, an alarm is initiated. The preset level can be different for each zone.

The alarm circuitry provides local and remote alarm indication. Equipment malfunctions are also indicated by the alarm circuitry.

The air sampling system (fig. 1) consists of sampling heads located in each room or area to be monitored and associated plumbing to the central cabinet (fig. 2). Each sampling head has a coarse dust filter and a means for adjustment of the flow. The lines from the four zones terminate in a manifold which is connected to the air sampling blowers. These blowers draw at least 2 cfm continuously. The above-mentioned manifold is part of a specially designed air selector valve operated by a cam shaft driven by a synchronous motor. The air selector valve opens and closes valves, sequentially connecting zones 1, 2, 3, and 4 to the measuring system. Each zone is connected to the measuring system for 15 seconds of every minute. The air selector valve also contains electrical contacts which are operated simultaneously with the valves. These contacts are used to select the alarm set point for each zone and for alarmed zone identification.

The measuring system (figs. 3 and 4) consists of the following components:

1. Humidifier
2. Rotary Valve
3. Cloud Chamber
4. Vacuum Pump
5. Sensor Circuit
6. Water Level Control Circuit

The air sample from the air selector valve is drawn through the humidifier which increases the air sample relative humidity to nearly 100 percent. The rotary valve controls the air sample flow to the cloud chamber. The vacuum pump provides the means for drawing the air sample through the cloud chamber and also for providing the reduced pressure to form the cloud in the cloud chamber. The density of the cloud is monitored by the solid state photo-detector. The output of the photodetector is measured by the sensor circuit. The water level circuit automatically controls the water level in the humidifier.

The operation is as follows: The vacuum pump draws a sample of air through the humidifier, rotary valve, and cloud chamber. The rotary valve then closes off the connection from the humidifier to the cloud chamber. The connection to the cloud chamber is also sealed off. After a brief settling time (milliseconds), the connection to the vacuum pump is reopened. This drops the pressure in the cloud chamber, and a cloud is formed. The rotary valve then opens the line to the humidifier, and a new air sample is drawn into the cloud chamber. The complete time for sampling and measuring is

1 second. Therefore, a signal is produced by the photodetector once each second.

The signal from the photodetector is amplified and, if the level is above a predetermined value, a pilot relay is closed. If this pilot relay is closed continuously for 10 seconds, the alarm relay will be closed. This relay signal is used to actuate other relays which light the front panel zone alarm indicator and provide a contact closure for transmission of the alarm signal.

A portion of the sensor circuit is used for self-checking of the measuring system. When a material is burned, extremely large concentrations of submicron particles are generated, referred to as the invisible products of combustion. Since submicron particles are always present in the air, the purpose of the malfunction circuit is to give an alarm in the absence of a signal from the cloud chamber. Therefore, a malfunction signal would occur whenever there was a failure of the vacuum system, rotary valve system, light source, power supply, photodetector, water supply, sensor circuit preamplifier, or lamp compensation circuitry. If the signal is too low because of an extremely clean environment, the malfunction light will also come on. A particle generator supplied by the manufacturer is installed on systems located in such environments but was not required in this test program.

The power requirement for the CNFD as tested was nominal line voltage (110 - 120 volts AC) with a maximum current requirement of 1 amp.

Condensation Nuclei Fire Detector Test Configuration

Pyrolyzer.-- Preliminary tests indicated that the CNFD was very sensitive to visible fire sources, but somewhat insensitive to smoldering sources. At this time the manufacturer indicated that a prototype pyrolyzer was available that would significantly increase the CNFD's sensitivity to smoldering plastics.

According to the manufacturer, cloud chamber theory, and preliminary tests, the CNFD is more sensitive to large numbers of small particles than to large visible particles; therefore, the operational improvement provided by the pyrolyzer is one of breaking up large particles from a smoldering source into a significantly greater number of smaller particles by impinging the gas sample stream on and around a hot filament. A report entitled "Physical Properties of Smokes Pertinent to Smoke Detector Technology", November 1977, by Thomas G. K. Lee and George Mulholland of the National Bureau of Standards, substantiates the validity of this theory based on numerous experiments and analyses. The manufacturer's prototype pyrolyzer was obtained and preliminary tests demonstrated a significant improvement in the CNFD's response to smoldering plastics with the pyrolyzer in operation. The pyrolyzer was used for all tests covered by this report. Energy required for the pyrolyzer is approximately 18 watts. Effects of the pyrolyzer on existing background levels resulting from normal dust levels, particles from previous tests, etc., did not result in any

detectable increased output of the CNFD photoelectric circuit; i.e., the pyrolyzer did not tend to increase the false alarm propensity of the system.

Sensitivity adjustment.- The sensitivity of the CNFD to alarm can be adjusted by changing specific resistances in the alarm circuitry. Based on the manufacturer's input, the test unit was set up with a series of resistors on a circular switch so that tests could be conducted at various sensitivities. Ten steps of sensitivity were used from maximum sensitivity (10K particles/cc) to a theoretical alarm level of 300K particles/cc. A series of tests were initially conducted to evaluate the effects of changing the sensitivity level on alarm response. Since the CNFD response was not significantly affected by the sensitivity setting and all of the units installed by Webb, Murray & Associates, Inc., were at a sensitivity level of 30K particles/cc, tests covered by this report were conducted at the 30K sensitivity level.

Photoelectric Detector

Manufacturer and Model - Pyrotronics,
Cedar Knoll, New Jersey, DP-3

Four state-of-the-art photoelectric smoke detectors were utilized in this program. The detector used combines a solid state light-emitting diode (LED) and a light-sensing photodiode arranged in a labyrinth sensing chamber. When smoke enters the sensing chamber, light emitted by the LED is scattered by the smoke and received by the photodiode. The electrical signal produced by the photodiode is amplified by the detector control circuitry and compared to a preset alarm threshold level. When the alarm signal level is reached, a 3-second delay cycle is initiated for protection against false alarms. At the end of the delay cycle, if the alarm level signal is still present, the detector goes into alarm. The unit's electrical sensitivity is factory set, but it was within the manufacturer's specified range verified by using the manufacturer's provided test unit.

Ionization Detector

Manufacturer and Model - Pyrotronics,
Cedar Knolls, New Jersey, DI-4A

Four low voltage state-of-the-art ionization smoke detectors were utilized in this program.

The detector used was a dual chamber ionization detector with adjustable sensitivity operating on the ionization principle. The unit contained two ionization chambers, together with a semiconductor amplifier-switching circuit. One chamber detects the presence of combustion products. The second chamber serves as a reference to stabilize the detector's sensitivity for local changes in temperature, humidity, and pressure. The detector used has a three-step manual adjustment setting for sensitivity which was set at its midpoint for all tests. Voltage output was verified to be

within manufacturer's specification before and after the test program.

Data Acquisition

The primary parameter for this test program was an accurate chronological record of events starting with the application of power to the products of combustion source. The two significant events for each detector were a positive indication of its alarm response during each test and an accurate measure of the elapsed time between application of power to the particle source and the alarm signal. These objectives were accomplished by the use of a cumulative stop watch and a consolidated signal light panel that included alarm signal lights for each detector. Figure 4 is a block diagram of the detectors and equipment used during each test. Each detector in the test room is connected to an alarm light panel which facilitated the annotation of alarm times for each detector. Also shown in figures 4 and 5 is the power supply for the products of combustion source. Figure 5 is a photograph showing the CNFD cabinet on the right and equipment associated with the test program mounted on a movable panel. This allowed access to the test room between tests and then when moved into the opening, the panel sealed off the room during testing. Color movies (16mm) were made which document the test setup and include two smoldering plastic tests and one visible fire test with concurrent alarm response. A thermo-humidigraph and sling psychrometer were used for monitoring temperature and humidity for each test. Airflow measurements for duct tests and balancing the four zones) of the CNFD were accomplished with the airflow meter.

Instrumentation

Specific instrumentation used during this test program is listed below:

- a. Stopwatch - Cronus 3-S
- b. Thermo-humidigraph - Range: 255 to 311 K (0 to 100 °F), 0 to 100 percent relative humidity (RH). Continuous recording on 7-day round chart.
- c. Sling psychrometer - Stortz - Range: 10 to 100 percent RH.
- d. Airflow meter - air velocity - Range: 0 to 2.54 m/s (0 to 5000 fpm)
- e. Condensation Nuclei Monitor (particle counter) - Model Rich 200 - Range: 50 to 10^6 particles/cc. (No particle size distribution capability)

Items b and d were calibrated by the Johnson Space Center calibration laboratory.

TEST CONFIGURATION

The geometry of the room in which all tests were conducted is shown in figures 6 and 7. Airflow inlets and outlets and detector zone locations are also shown in these figures. Arrangement of the detectors and sampling heads on a panel is shown in figure 8. These panels were 0.61 by 0.61 m (2 by 2 ft) square as were the ceiling tiles and computer floor panels to facilitate installation at either level and at selected positions in the room. Zones 1 and 2 were selected as moderately stagnant areas and zone 3, located between a supply and return air grill, had fairly high airflow. In figure 6, zone 4 was located in the 0.23 by 0.31 m (9 by 12 in) duct (except for underfloor tests) and, in addition to being used for the duct tests, it provided a stagnant air region for all other tests since the duct blower was not operating except during duct tests. Details of the duct arrangement and zone 4 are shown in figure 9. The relocation of zone 4 for underfloor tests is shown in figure 6.

Figure 10 is a photograph across the test room showing zones 1 on the left and 3 on the right. Also, note minor barriers to lateral smoke flow across the ceiling in the north-south direction caused by the 10.16-cm (4-inch) light fixture intrusion into the room. The heater for products of combustion from plastic sources is located on the floor and is shown in greater detail in figures 11 and 12. Figure 13 shows the configuration for paper products of combustion tests.

Test Criteria

In order to meet the the primary objective of this program for determining if the CNFD is superior to currently used smoke detectors, several criteria were developed and followed during the testing:

1. Each of the four zones of the CNFD were setup in close proximity to current state-of-the-art photoelectric and ionization detectors so that each detector type in any particular zone would be exposed to the same environment such as smoke density, temperature, humidity, and airflow.
2. Established tests such as those used by Underwriter Laboratories were not used for several reasons.
 - a. Since each of the detector systems used in the test program had already passed the Underwriter Laboratory tests, further utilization of these tests would be redundant.
 - b. Those defined tests involve more than one fuel and usually start out with visible fire rather than nonflaming pyrolysis such as might be expected from smoldering electrical insulation.
 - c. Underwriter Laboratory tests do not require variations in temperature and humidity. Varying these conditions were

considered necessary for this test program because of the particle sensing technique used by the CNFD.

3. Products of combustion sources were selected that in one case would produce predominantly large visible particles such as from smoldering plastics and in the other case many small nonvisible particles as are generally produced by visible fire.

4. The product of combustion source was kept small to indicate any true incipient detection capabilities of each of the systems tested. Additionally, the small size was developed to provide significant discrimination between the various systems rather than a rapid but less discriminatory response.

A review of the literature and discussions with experts in the field of fire detector testing indicated that full-scale comparative testing, especially with small smoldering sources, had not previously been done.

Products of Combustion Sources and Characterization

As described in the Test Criteria, two general categories of products of combustion sources were defined in the test plan which were further refined in preliminary tests.

Smoldering Plastic

Since many electrical power supply cables are insulated with polyvinyl chloride, cable of this type was selected as one product of combustion source. The cable had an overall diameter of 4.1 mm (0.16 in) and was made up of two pairs of 22 gauge wires with an outer polyvinyl chloride jacket that was 0.48 mm (0.019 in) thick.

The amount used for each test was 0.91 m (3 ft) in length cut in short pieces so it would fit into the ceramic crucible (fig. 12). After application of power, approximately 60 seconds elapsed prior to visible smoke evolution. For 120 to 180 seconds, the production of a light gray smoke became denser and good smoke production continued to the 600- to 720-second point. From this point, there was a gradual reduction with some evolution of smoke continuing through 900 seconds. This resulted in an actual weight loss of an average of 9 g of material during each test. The second common material used was approximately 4 g of flexible polyurethane foam compressed and constrained with nichrome wire and pyrolyzed in the ceramic crucible. Evolution of smoke from the foam was also delayed 60 to 120 seconds while the crucibles and material heated up. The smoke evolved was a bright yellow green which ceased at 300 to 360 seconds because of material depletion. Additionally, several tests were conducted with urethane paint potted and cured in the crucible (5.5 to 10 g) to determine if material configuration was a factor in detector response time for urethanes. The smoke from the urethane paint was less dense and more of a gray color compared to the smoke from the foam. Smoke production again was for 300 to 360 seconds.

Visible Fire

Computer paper was used for several tests as were washroom paper towels. Ten sheets of computer paper (approximately 75 g) were used for most tests, and one sheet (8 g) was used in one test (fig. 11). Twenty to forty washroom towels were used for several tests also. Both types of paper burned clean for 90 to 120 seconds. Ignition took from 10 to 20 seconds and on occasion, if the paper was not in good contact with the filament, large puffs of smoke evolved prior to visible fire. The single sheet of paper in one test was consumed in approximately 10 seconds.

Acetone was used for several tests as a hydrocarbon representative. It was selected because of its flammability without significant production of visible smoke.

Test Termination Criteria

Smoldering Plastic

Since the objective of the smoldering plastic products of combustion tests was to obtain results without visible fire, tests in which the material caught fire were aborted and not included in this report. The selected voltage and amperage prevented ignition, except for a few tests involving the urethanes. Tests were terminated at the end of 900 seconds since all indications (visible smoke in the room and observed smoke from the crucible) were declining by this elapsed time. The measured particle density had stabilized or was declining by the end of 900 seconds. Preliminary tests conducted for longer periods of time did not result in additional alarms.

Visible Fire

The quantities of fuel used in these tests were usually consumed in 120 seconds or less, and the particle count was rapidly declining from 120 to 180 seconds. Therefore, these tests were terminated at the end of 300 seconds.

RESULTS AND DISCUSSION

SMOLDERING POLYVINYL CHLORIDE (PVC)

Table I is a compilation of nonflaming (smoldering) tests conducted using plastic materials. This table presents results of tests conducted and indicates opportunities for alarm versus number of alarms occurring. The average time to alarm and standard deviations for the three detector systems involved in each test is also presented in the table. The following discussion and related figures follow the order outlined in table I.

Environmental Effects

Tests were conducted to determine the effects of a range of temperatures and humidities on the CNFD since the cloud chamber phenomena is based on condensation of moisture on smoke particles serving as nuclei. Since the building utilized for these tests had some infiltration of outside air, a wide range of relative humidities existed as shown in table I. As would be expected, higher humidities existed in the summer and lower humidities in the winter months. The broad range of conditions encountered was not only considered acceptable, but also desirable from the evaluation standpoint.

The detector response to PVC for the three environments is shown in figure 14. Overall, the best alarm response for all detectors was under the cool conditions with a decline in response for photoelectric and ionization at ambient and warm conditions. The CNFD had 100 percent response at both cool and ambient conditions with a decline to 76 percent at the warm conditions.

Since each of the detection systems tested is affected to some extent by changing the test environment, the reduction in response may be caused by the reduction of convective forces on the generated smoke as the room temperature is increased, rather than a specific effect on the smoke or changes in the detector's efficiency. The time to alarm differences between the CNFD and photoelectric detectors (table I) is not significant after considering the standard deviations to response times.

Low Air Movement

Some tests were conducted with all of the air-handling equipment turned off in the test room so that air movement within the room was negligible. In figure 15, the alarm response of both photoelectric and ionization detectors is increased with low air movement. The higher response with low airflow may be attributable to two factors:

1. Initial smoke dilution with clean air results from the fairly large volumes of clean air being introduced to the room from both above the ceiling and below the floor when the air handlers are on. This clean air is eventually recycled to the room, but still considerably diluted because of the significant volume of the above ceiling and below floor regions as well as in the ductwork to the air conditioning equipment on the roof and on the first floor.

2. Reduction of interference of incoming air with convective movement of the smoke to the ceiling and subsequently to the detectors by incoming air.

Smoke Source Moved Away From Room Center

For three tests, the smoke source was moved away from the center to two extreme corners. No significant effect was noted for the CNFD or the photoelectric detectors (with ambient conditions and airflow on) in response efficiency (fig. 15). The ionization detectors did not alarm during these tests. However, their usual response at ambient conditions with airflow was quite low, and failure to alarm for this series may be due to the limited number of opportunities.

High Airflow Tests

Since problems sometimes occur when smoke detectors are installed in high airflow regions, several tests were conducted in a duct arrangement (figs. 6 and 9) for the primary purpose of evaluating the three detector techniques (zone 4) at various high airflows. None of the three detection systems in the test program were specifically designed as duct detectors. All detector results (in room and duct) for high airflow tests are included in table I and in figure 16; whereas, specific results for the detectors in a duct only (zone 4) are presented in table II.

Overall Results In-Room and In-Duct

The results for all detectors during the high airflow tests are shown in figure 16. A reduction in response was evident when the smoke source was moved away from the room center. This was primarily due to the duct intake location which is almost directly above the room center. During those tests, much of the smoke generated was picked up by the intake and distributed throughout the room, thus insuring good detection. With other locations of the smoke source, distribution was less efficient and some detector locations did not receive sufficient smoke for alarm.

These in-room results are included for comparative purposes only, since the high additional airflows associated with the duct tests (in addition to the normal room ventilation) are not typical of most room airflow environments that might be encountered.

Response in Duct

Results of the response of detectors in the duct itself (zone 4) are shown in table II. Air velocity in the duct, CNFD sample head geometry, smoke source, and alarm response times are given. The ionization detector always went into alarm at air velocities of 3.56 m/s (700 ft/min) and above, as a result of the high airflow. The photoelectric detector did not go into alarm as a result of any of the air velocities used. The ionization detector had only one valid alarm response in this test series.

Underfloor Tests

Several tests were conducted with the detector panels installed in the floor directly under the ceiling location for room tests (zones 1, 2, and 3) with zone 4 installed as shown on figure 6. The smoke source was located under the floor for these tests.

No Airflow

The underfloor volume is approximately 21 percent that of the room volume; therefore, smoke densities under the floor with the same smoke source should approach five times that in the room under no airflow conditions. Both the CNFD and the photoelectric detectors alarmed to all opportunities for this condition (fig. 17). The response of the ionization detector was higher for these tests (50 percent) than for any other smoldering smoke source test.

Airflow On

The general underfloor airflow path with all air handlers on is from the one underfloor supply inlet shown in figure 6 and into the room through the rectangular floor supply grills shown on the same figure. As indicated in table 1 and figure 17, alarm response of the photoelectric and ionization detectors was generally higher than for most other tests with the PVC insulated wire, again due to the higher smoke density. In this series of tests, all detectors in zone 3 alarmed for each test probably due to a high smoke density in this region because of its proximity to the smoke source. Zone 4 was the next most responsive with the photoelectric and CNFD alarming for each test. For zone 2, there was no ionization alarm response, two photoelectric alarms, and seven CNFD alarms. Zone 4 had seven CNFD alarms only. These results probably occurred due to a higher concentration of smoke in zones 3 and 4 with a greater response for the photoelectric and ionization detectors. A lower response occurred in zones 1 and 2 for all detectors, which resulted in a fairly high percentage of response for the photoelectric and ionization detectors and less than 100 percent for the CNFD.

Relocation of Smoke Source

When the PVC insulated wire smoke source was moved to each of the four corners of the room under the floor, the alarm response was considerably reduced for all detectors as shown in figure 17. This is simply a result of floor grill versus smoke source geometry preventing smoke from getting to all detectors, or in some cases, to any of the detectors at a high enough density to result in alarms. Where the floor grills are between the detectors and the smoke source, some significant portion of the smoke is exhausted out of the underfloor volume before getting to the detectors which are shown in figures 7 and 8.

SMOLDERING URETHANES

Several tests were conducted using 4 g of polyurethane flexible packing foam and cured urethane paint (5 to 8 g). A comparison of typical particle densities for the three materials tested is shown in figure 18. Less urethane compared to PVC resulted in much higher particle counts which is only partially due to a somewhat higher pyrolysis rate. The urethane paint was tested to see if the large area-to-mass ratio was the primary factor causing higher particle levels of polyurethane foam compared to polyvinyl chloride. This appears to be a partial contributing factor; however, the solid urethane paint still produced particle concentrations much higher than the PVC which indicates that some basic material factor is also involved. In figure 19, the trend of declining response from cool through ambient to the warm environment is more pronounced for the urethane compared to the PVC. The alarm response for both the photoelectric and ionization detectors is reduced under all three conditions despite the higher indicated particle density.

VISIBLE FIRE

Tests were conducted with cellulose materials and one hydrocarbon liquid fuel to evaluate the smoke detectors when exposed to flaming sources that produce low levels of visible smoke. Fuel identification and quantities are shown in tables III and IV. The previously-cited reference presents measured results of particle size distribution for cellulose. This indicates that the size distribution of smoke aerosols is influenced by whether the pyrolysis is flaming or smoldering. Larger quantities of small particles are produced by flaming sources which is also substantiated in figure 20 which shows typical particle concentrations for visible fire and smoldering PVC. The results presented in table III for flaming source response time (54 to a maximum time of 91 seconds) for all systems tested is considerably shorter than for smoldering PVC or urethane. In figure 21, predominant response is from the CNFD and ionization detectors; whereas, with smoldering sources, predominant response is from the CNFD and photoelectric detectors. The comparison of the results from the condensation nuclei monitor for flaming and smoldering combustion presented on figure 20 shows that the particle buildup for flaming sources is quite rapid for the paper or acetone fires compared to smoldering plastics. The total quantities of materials consumed and the rates were significantly higher with the flaming sources compared to smoldering. Therefore, these curves are only of value in providing an indication of why the alarm times are significantly different for the two types of pyrolysis.

Particle counts for smaller fuel sources for paper and acetone are shown in figure 22. Again, because of the rapid combustion rate, the peaks are quite high. However, the duration at high levels is considerably reduced, and the particle concentration decay is rapid with a reduction in material consumed. This may explain why, even with these high levels, detection was not 100 percent for the CNFD or ionization detectors. First, the CNFD takes 60 seconds

to interrogate all four zones; so if it missed the high level on the first interrogation, the level may have dropped the second time around. In fact, for 20 g of acetone, only zones 2 and 3 of the CNFD alarmed. For 8 g of paper, zones 1 and 2 of the CNFD were the only ones to alarm. Secondly, the particle count is only measured at one zone per test (zone 1 for these tests). The levels at the other zones are not measured and may be considerably less.

DILUTION EFFECTS

Since the CNFD can have up to 10 sampling heads per zone with samples originating in 10 separate locations (according to manufacturer's recommendations), a sample could be considerably diluted with clean air from other regions prior to being pumped back to the CNFD. All preceding tests were conducted with each zone having 50 percent of the sample taken from the test room diluted with 50 percent clean air. Theoretically, this meant that the CNFD would not alarm until the particle level in the test room reached 60K particles/cc with the sensitivity of the CNFD set to alarm at 30K particles/cc.

Since it is desirable to know how much dilution the CNFD could accommodate for the smoke sources being used, two series of dilution tests were conducted. Results of these tests for paper (flaming) and PVC (smoldering) are shown in figure 23. For paper, the response from 0 to 70 percent dilution is almost vertically linear. This indicates that if at least three sampling heads out of 10, or 30 percent of whatever sampling configuration is used, the CNFD would alarm in that zone. Above 70 percent dilution, the response starts falling off significantly. The same relationship occurs for the smoldering PVC except that the alarm response for 0 to 70 percent dilution, though linear, does increase in average time to alarm from 315 to 450 seconds.

SUMMARY OF TEST RESULTS

Response results for all tests are summarized in figure 24.

Smoldering Plastic

For the smoldering plastic tests, the CNFD alarmed to 90 percent of 440 opportunities, the photoelectric detectors 43 percent, and the ionization detectors 9 percent.

Visible Fire

For visible fire, the CNFD responded to 84 percent of 112 opportunities, the photoelectric detectors to 12.5 percent, and the ionization detectors to 48 percent. This is a reversal of the photoelectric detector's response for smoldering plastics.

Overall Results

The overall program resulted in the CNFD responding to 89 percent of a total of 552 opportunities, the photoelectric detectors to 37 percent, and the ionization detectors to 17 percent. These percentages are biased towards the smoldering plastic results since 80 percent of all tests conducted were with the smoldering plastics.

Alarm Times

The average time to alarm for all detectors responding to smoldering plastics (table I) is from 225 to 550 seconds. Average time for visible fire responses (table III) was much shorter, occurring in the first 120 seconds of the tests for all detectors responding. Overall no significant advantage accrued to any particular detector system regarding response time. Since the smoldering plastic source was an incipient threat only, it would not appear that time to response is nearly as important as the reliability of response. The smoldering plastic sources, burning paper (in a basket), or acetone did not produce a threatening environment during the 15-minute test period. Loss of visibility in the test room was almost nil although layers of smoke were visible. There was no detectable temperature rise. Although the test room air did not smell good, it did not cause any respiratory or eye irritation on the one or two occasions the room was entered at test completion.

At the end of the test program after 200 tests, there was no visible deposition of smoke residue on the room walls, ceiling, or floor, or on equipment installed in the room. An aluminum sheet installed horizontally on the ceiling directly above the smoke source to prevent the accumulation of smoke deposits on the ceiling did have a minor amount of visible corrosion on the surface.

RELATED RESULTS

Background Particle Levels

Background particle levels encountered in the test area did not appear to have significant effects on detector response times. Tests were started as long as the room level particle count was below 20K particles/cc. The condensation nuclei monitor indicated large quantities of particles for visible fires and much lower quantities for smoldering sources. This was consistent with reports in many previous test programs presented in various technical papers. The high levels, when sustained, did not always result in response of the CNFD or ionization detectors, indicating that another factor such as particle size is probably involved. One CNFD unit was temporarily installed in a cyclically active-inactive computer room and test area along with the condensation nuclei monitor. Alarms did not occur during this relatively short exposure time (2 weeks) and indicated particle levels ranged from 5K to 30K particles/cc. Because of this limited experience, it is planned to install the CNFD in the same area where the test program was conducted. The test room is being converted to a central computer facility for a very active test organization. The area will include offices and

electronic work areas so a fairly broad spectrum of particle backgrounds will be encountered. Smoking is permitted throughout the area resulting in an environment which is more difficult to deal with from the undesirable alarm standpoint because of the sporadic generation of large quantities of small particles.

Test Program Maintenance Experience

On approximately eight occasions during the test program, the CNFD malfunction light was found to be on at the start of the test day. On two occasions, this was found to be caused by air in the water supply line to the humidity chamber which also prevented the unit from being responsive to smoke (no moisture for condensation of nuclei). On the other occasions, the problem was caused by very low background levels which do not affect the operation of the unit and was eliminated by lighting a cigarette. The manufacturer provides an add-on fix for this problem called a particle generator which is a small resistance heater with silicone oil as the particle source. The unit under test did not have this feature.

An eventual maintenance problem occurred after approximately 100 tests were conducted due to material deposits in the CNFD. This problem was manifested by an increase in the normal output of the CNFD photo detector circuit. A thorough internal cleaning of the humidifier, rotary valve, and optic surfaces eliminated this problem and put the system back within the original specifications regarding flow rates, line vacuum pressures, and voltage outputs. These deposits were a result of the test environment and would not occur in the typical clean area installation; however, for an installation in dirtier areas, some periodic cleaning frequency might be required. The cleaning requires a trained individual work 10 to 15 hours with no special restart requirements other than turning the system on.

On another occasion, system sensitivity was lost because of a leak in the pyrolyzer. Any leak between the selector valve and cloud chamber will adversely affect the sensitivity because of significant sample dilution.

Industry Maintenance Experience

Although not a part of this test program, industrial maintenance experience with the CNFD is of interest to anyone contemplating utilization of this system for fire protection. Some of the relative experience is included in the Appendix to this report.

Potential Design Changes

Several areas of the CNFD and add-ons are candidates for design improvements either to improve the system or eliminate the add-on.

Pyrolyzer

The pyrolyzer, which proved to be essential for CNFD response to smoldering plastic, is in need of design improvement in its current configuration. It is bulky and the box enclosure not conducive to mounting on the CNFD panel. The filament is installed in a glass tee which requires a glass-to-metal seal. A rubber cork with pin feed-throughs to the filament is inserted in the tee. Late in the test program, the cork started popping out which resulted in complete loss of sensitivity due to dilution with clean air. This was corrected by wiring the cork to the tee. The volume in the pyrolyzer was excessive which on occasion caused carry over of smoke from a smoky zone to a clean zone. This was eliminated by minimizing the inlet and outlet line lengths between the pyrolyzer and CNFD. The unit includes a variable rheostat to permit the option of pyrolyzing the gas from one zone only or from all four zones; however, based on the results of this test program, it would appear that all four zones should always go through the pyrolyzer which would eliminate any need for the variable rheostat. The pyrolyzer as designed is powered separately from the CNFD so that if the CNFD loses power, the pyrolyzer filament would probably burn out because of the loss of cooling from sample flow over the filament. The filament itself, although temporarily shorted out several times when the cork popped out, survived the test program without requiring replacement.

Particle Generator

Although not required in this program, other applications in very clean areas have mandated a manufacturer-supplied particle generator to keep the malfunction light off. This add-on can potentially cause problems through loss of power to the heater, leakage, and becoming nonfunctional through failure to add silicone oil at the appropriate time. It adds an undesirable requirement of maintenance to the CNFD.

CONCLUDING REMARKS

The comparative evaluation of the CNFD with photoelectric and ionization detectors included a total of 138 tests or 552 alarm opportunities.

The CNFD was significantly better than the other detectors for all of the conditions the systems were exposed to such as various environments, different airflow conditions, and relocation of smoke sources. With the prototype pyrolizer, the CNFD was an excellent detector for small smoldering plastic sources which appear to be one of the more difficult incipient fires to detect.

Response times were variable and there was not a significant difference between the three systems tested when looking at overall average times. Unexpected false alarms were not a problem with any of the systems tested; however, this area undoubtedly needs more evaluation in an active environment especially for the CNFD.

A range of temperatures and humidities had some effect on each of the systems. However, these variations do not appear to be significant in reducing the reliability of the detectors.

High air velocities did not adversely affect the alarm response of either the CNFD or the photoelectric detector. However, as expected, the ionization detector went into alarm (in the absence of smoke) when directly exposed to higher air velocities.

Significant differences were noted in response and the particle density environment produced between PVC and urethanes suggesting that a broad spectrum of results might be encountered with the multiplicity of plastics currently in use.

Some particle measurements were made in occupied and unoccupied areas, and the CNFD was installed in the same location for approximately 2 weeks without false alarming. More exposure of this type is needed before reaching final conclusions.

With the inconclusive time to alarm variability between the three systems, the much higher reliability response of the CNFD and its lesser sensitivity to installation error would support its choice for applications where either smoldering or visible fire could occur.

Maintenance requirements of the CNFD were not severe during this test program. Some areas of the system do need improvement based on problems encountered and observations made. Commercial experience with the CNFD has revealed repetitive problems especially in clean environments concerning the malfunction circuitry that indicates a need for improvement.

CNFD RESPONSE

The CNFD with a pyrolyzer responded well to both smoldering plastic sources (90 percent) and visible fire (84 percent) which could allow it to replace both photoelectric and ionization detectors. Because of its positive action of pumping samples back to a central system for interrogation, it was not overly sensitive to location with respect to smoke source position in the room and also was very responsive in both stagnant airflow areas and high airflow regions such as might be experienced in air conditioning return air ducts. Dilution of smoky air with clean air, as might be encountered with 10 sampling heads per zone, was not an alarm deficiency problem for the CNFD until 70 percent dilution with clean air was experienced. The CNFD's good response to smoldering plastics was only evidenced when a prototype pyrolyzer was used with the system. The pyrolyzer is a candidate for design simplification and repackaging. Additionally, test results indicated that the CNFD would alarm throughout its broad range of sensitivity, permitting its use in various background particle environments.

PHOTOELECTRIC DETECTOR RESPONSE

The photoelectric detectors responded 43 percent of the time to smoldering sources and 12.5 percent to flaming sources. They only responded to visible fire when ignition was delayed, causing an initial production of visible smoke.

IONIZATION DETECTOR RESPONSE

The ionization detector's response to smoldering plastic sources was only 9 percent. Its response to visible fire was higher at 48 percent indicating that it is primarily only responsive to fire threats after they have burst into flame or to larger smoldering sources than were used in this program.

RECOMMENDATIONS FOR ADDITIONAL WORK

CURRENT DESIGN OF CNFD

The system should be reviewed to determine if it can be improved in areas such as those now containing mechanical relays, improvement of power supply, elimination of the need for a particle generator regardless of environment, and improved alignment and mounting of the photoelectronics. The propensity of some of the CNFD systems to indicate a malfunction due to very clean environments also needs to be eliminated. The humidity chamber also appears to be a candidate for improvement to insure efficient humidification of air samples and elimination of system flooding.

Pyrolyzer

Since the sensitivity of the CNFD to smoldering plastics is contingent on having a pyrolyzer in the system and the existing unit is a nonrefined prototype, it is recommended that design simplification and repackaging be accomplished. Areas to pursue are elimination of glass tubing, elimination of a variable resistor, containment of the filament on a ceramic rod, and packaging the unit in a box that can be mounted on the side or top of the CNFD control panel.

FUTURE APPLICATIONS

Space Station

Since the CNFD is more responsive to both smoldering plastics and visible fire than other state-of-the-art detectors, it is recommended that this system be considered for use on the space station. The feature of having centralized electronics would simplify checkout and maintenance of the system. The capability of retrieving samples from at least 48 m (150 feet) away with simple plumbing again enhances its applicability to the space station. Reliability of response and excellent response to smoldering wire insulation make the CNFD particularly applicable to space utilization.

Effort required would be redesign of the electronic and mechanical systems utilizing space qualified components and qualification of the unit for the planned launch and orbital environments. Although it does not appear that zero-g would have any effect on cloud chamber phenomena, the current design of the humidity chamber with free water in the bottom would not work in zero-g. Design changes in this area need to be made.

Passenger Aircraft

Despite the excellent safety record of commercial passenger aircraft, a need still exists for improved smoke detection in unattended areas such as cargo bays, lavatories, and the loft regions above the passenger cabin.

The effort required would be similar to that for space application with somewhat different dynamic environments involved.

This effort should only be pursued if the Federal Aviation Administration and the aircraft industry indicate an interest and potential need.

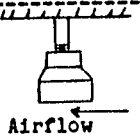
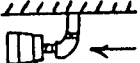
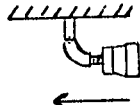
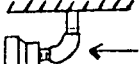
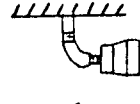
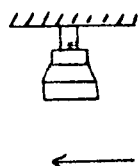
TABLE I
ALARM RESPONSE FOR
NONFLAMING PYROLYSIS

| TEST SERIES Ambient Temperature, Humidity, and Airflow, Except as Otherwise Noted | OPPORTUNITIES (TESTS) | CNFD | | PHOTOELECTRIC DETECTORS | | IONIZATION DETECTORS | |
|---|--------------------------|-------------------------|-----------------------------------|-------------------------|-----------------------------------|-------------------------|-----------------------------------|
| | | Number of Alarms (%) | Average Time \pm Std.Dev. | Number of Alarms (%) | Average Time \pm Std.Dev. | Number of Alarms (%) | Average Time \pm Std.Dev. |
| A. 3 Feet PVC Insulated Wire (9 gms) | | | | | | | |
| 1. Center Floor Source | | | | | | | |
| a. Ambient Conditions | 108 (27) | 108 (100) | 445 \pm 146 | 56 (52) | 408 \pm 112 | 4 (4) | 342 \pm 13 |
| b. Cool Temp. 280 K (45°F) 30 - 50% RH | 52 (13) | 52 (100) | 382 \pm 114 | 35 (67) | 471 \pm 175 | 12 (23) | 503 \pm 140 |
| c. Warm Temp. 305 K (90°F) 8 - 42% RH | 68 (17) | 52 (76) | 473 \pm 150 | 18 (26) | 369 \pm 169 | 1 (1.5) | 239 \pm 0 |
| d. Ambient, Except All Air Off | 8 (2) | 8 (100) | 321 \pm 52 | 6 (75) | 501 \pm 153 | 2 (25) | 550 \pm 50 |
| 2. Location of Source Away From Room Center | 12 (3) | 12 (100) | 424 \pm 76 | 6 (50) | 468 \pm 141 | 0 | 0 |
| 3. Duct Tests | | | | | | | |
| a. Source in Room Center | 32 (8) | 32 (100) | 377 \pm 144 | 19 (59) | 407 \pm 164 | 2 (6) | 522 \pm 48 |
| b. Source At Other Than Room Center | 48 (12) | 37 (77) | 542 \pm 124 | 6 (12) | 462 \pm 138 | 0 | 0 |

TABLE I - Continued
ALARM RESPONSE FOR
NONFLAMING PYROLYSIS

| TEST SERIES Ambient Temperature, Humidity, and Airflow, Except as Otherwise Noted | OPPORTUNITIES (TESTS) | CNFD | | PHOTOELECTRIC DETECTORS | | IONIZATION DETECTORS | |
|---|--------------------------|-------------------------|-----------------------------------|-------------------------|-----------------------------------|-------------------------|-----------------------------------|
| | | Number of Alarms (%) | Average Time \pm Std.Dev. | Number of Alarms (%) | Average Time \pm Std.Dev. | Number of Alarms (%) | Average Time \pm Std.Dev. |
| 4. Source Center Underfloor | | | | | | | |
| a. Airflow Off | 12 (3) | 12 (100) | 326 \pm 89 | 12 (100) | 477 \pm 109 | 6 (50) | 528 \pm 195 |
| b. Airflow On | 36 (9) | 32 (89) | 352 \pm 143 | 20 (56) | 303 \pm 146 | 9 (25) | 287 \pm 61 |
| 5. Source Other Than Center Underfloor | 16 (4) | 9 (56) | 528 \pm 171 | 1 (6) | 239 \pm 0 | 0 | 0 |
| B. Polyurethane | | | | | | | |
| 1. Ambient | 28 (7) | 27 (96) | 251 \pm 64 | 6 (21) | 417 \pm 60 | 1 (4) | 550 \pm 0 |
| 2. Cool 282 K (48°F) 50% RH | 8 (2) | 8 (100) | 333 \pm 48 | 3 (37.5) | 440 \pm 78 | 2 (25) | 311 \pm 128 |
| 3. Warm 305 K (90°F) 8% RH | 12 (3) | 6 (50) | 321 \pm 56 | 2 (17) | 225 \pm 28 | 0 | 0 |
| Total for Plastic Smoke Source | 440 (110) | 395 (90) | - | 190 (43) | - | 39 (9) | - |

TABLE II
RESPONSE OF DETECTORS IN DUCT (ZONE 4)
FOR HIGH AIRFLOW TESTS
(AMBIENT TEMPERATURE, HUMIDITY)

| CNFD SAMPLE HEAD GEOMETRY | SMOKE SOURCE | DUCT VELOCITY | TIME TO ALARM(S) | | |
|---|---|------------------------|---------------------------|--------------------|------------|
| | | | CNFD WITH PYROLYZER | PHOTO- ELECTRIC | IONIZATION |
|  | 3' PVC Insulated Wire, Room Center on Floor | 12.7 m/s (2500 fpm) | 408 | 410 | * |
|  | Same as Above | 12.7 m/s (2500 fpm) | 416 | 408 | * |
|  | Same as Above Except Sample in Southeast Corner | 12.7 m/s (2500 fpm) | 465 | None | * |
|  | Same as Above | 12.7 m/s (2500 fpm) | 370 | 378 | * |
|  | 4 g Polyurethane Foam, Center Room on Floor | 12.7 m/s (2500 fpm) | 190 | 307 | * |
|  | 3' PVC Insulated Wire, Room Center on Floor | 3.6 m/s (700 fpm) | 374 | 443 | * |
| | | 2.5 m/s (500 fpm) | 358 | 415 | 543 |
| | | 1.5 m/s (300 fpm) | 325 | 412 | None |
| | | 1.3 m/s (250 fpm) | 353 | 422 | None |

*Immediate Alarm From High Airflow

TABLE III
ALARM RESPONSE FOR
FLAMING COMBUSTION
AND SUMMARY
(AMBIENT CONDITIONS)

| TEST SERIES | OPPORTUNITIES (TESTS) | CNFD With Pyrolyzer | | PHOTOELECTRIC DETECTORS | | IONIZATION DETECTORS | |
|--|--------------------------|-------------------------|-----------------------------------|-------------------------|-----------------------------------|-------------------------|-----------------------------------|
| | | Number of Alarms (%) | Average Time \pm Std.Dev. | Number of Alarms (%) | Average Time \pm Std.Dev. | Number of Alarms (%) | Average Time \pm Std.Dev. |
| Liquid and Solid Combustibles | | | | | | | |
| 1. Acetone (See Table IV for Detailed Tests) | 32 (8) | 20 (62.5) | 91 \pm 33 | 0 | 0 | 2 (6.2) | 70 \pm 12 |
| 2. Computer paper (75 gms) | 40 (10) | 38 (95) | 91 \pm 33 | 10 (25) | 63 \pm 27 | 25 (62.5) | 62 \pm 32 |
| 3. Computer paper (8 gms) | 4 (1) | 2 (50) | 54 \pm 13 | 0 | - | 0 | - |
| 4. Paper Towels (20 to 40) | 36 (9) | 34 (94) | 85 \pm 35 | 4 (11) | 66 \pm 24 | 27 (75) | 63 \pm 30 |
| Total for Flaming Combustion | 112 (28) | 94 (84) | - | 14 (12.5) | - | 54 (48) | - |
| Overall Totals | 552 (138) | 489 (89) | - | 204 (37) | - | 93 (17) | - |

TABLE IV
ALARM RESPONSE FOR ACETONE TESTS
(AMBIENT CONDITIONS)

| QUANTITY (GMS) | CONFIGURATION | OPPORTUNITIES (TESTS) | CNFD With Pyrolyzer | | IONIZATION DETECTOR | |
|-------------------|---|--------------------------|-------------------------|---------------------------------|-------------------------|------------------------------------|
| | | | NUMBER OF ALARMS (%) | AVERAGE TIME \pm STD. DEV. | NUMBER OF ALARMS (%) | AVERAGE TIME \pm STD. DEV. |
| 30 | 15.2 cm (6-in) Diameter Saucer | 4 (1) | 2 (50) | 77 \pm 10 | 0 | - |
| 30 | | 4 (1) | 3 (75) | 59 \pm 8 | 0 | - |
| 40 | | 12 (3) | 6 (50) | 56 \pm 12 | 0 | - |
| 60 | | 4 (1) | 3 (75) | 77 \pm 15 | 0 | - |
| 105 | 0.61 m by 0.61 m (2 ft by 2 ft) | 4 (1) | 3 (75) | 47 \pm 10 | 0 | - |
| 207 | With Ceramic Wick | 4 (1) | 3 (75) | 70 \pm 8 | 2 | 30 \pm 8 |
| Totals | | 32 (8) | 20 (63) | - | 2 (62) | - |

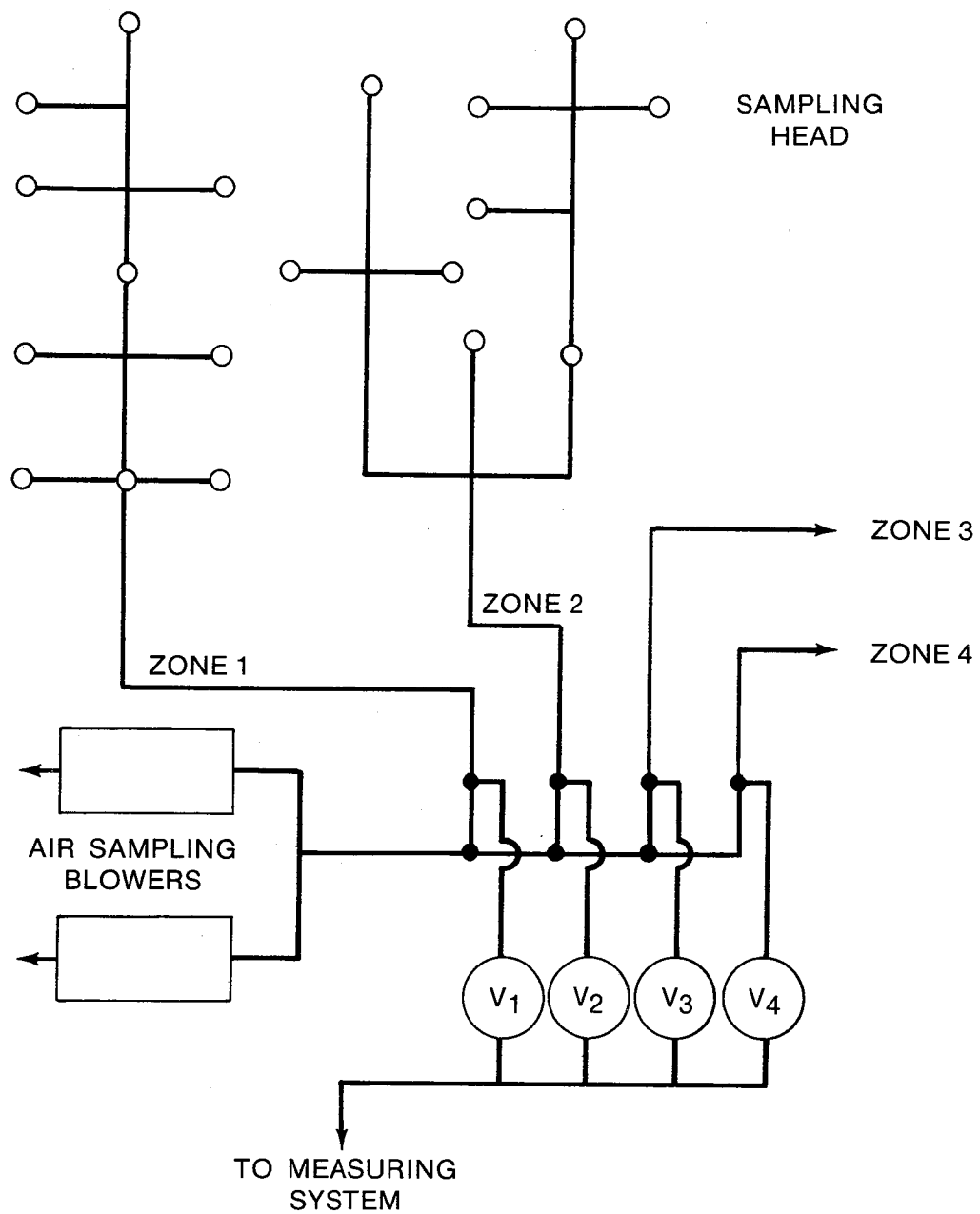


Figure 1. - Block diagram of air sampling system.

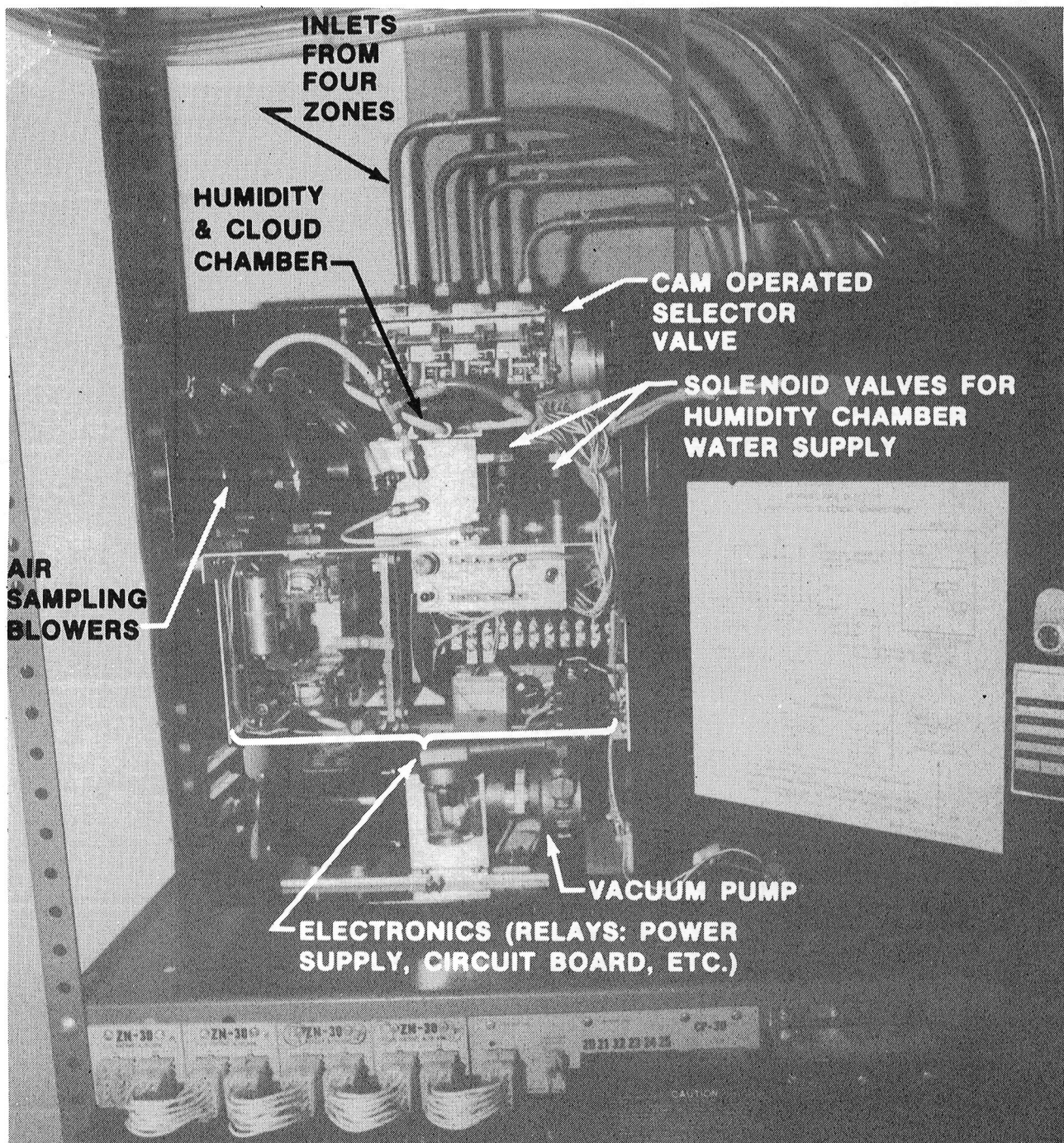


Figure 2. - CNFD cabinet.

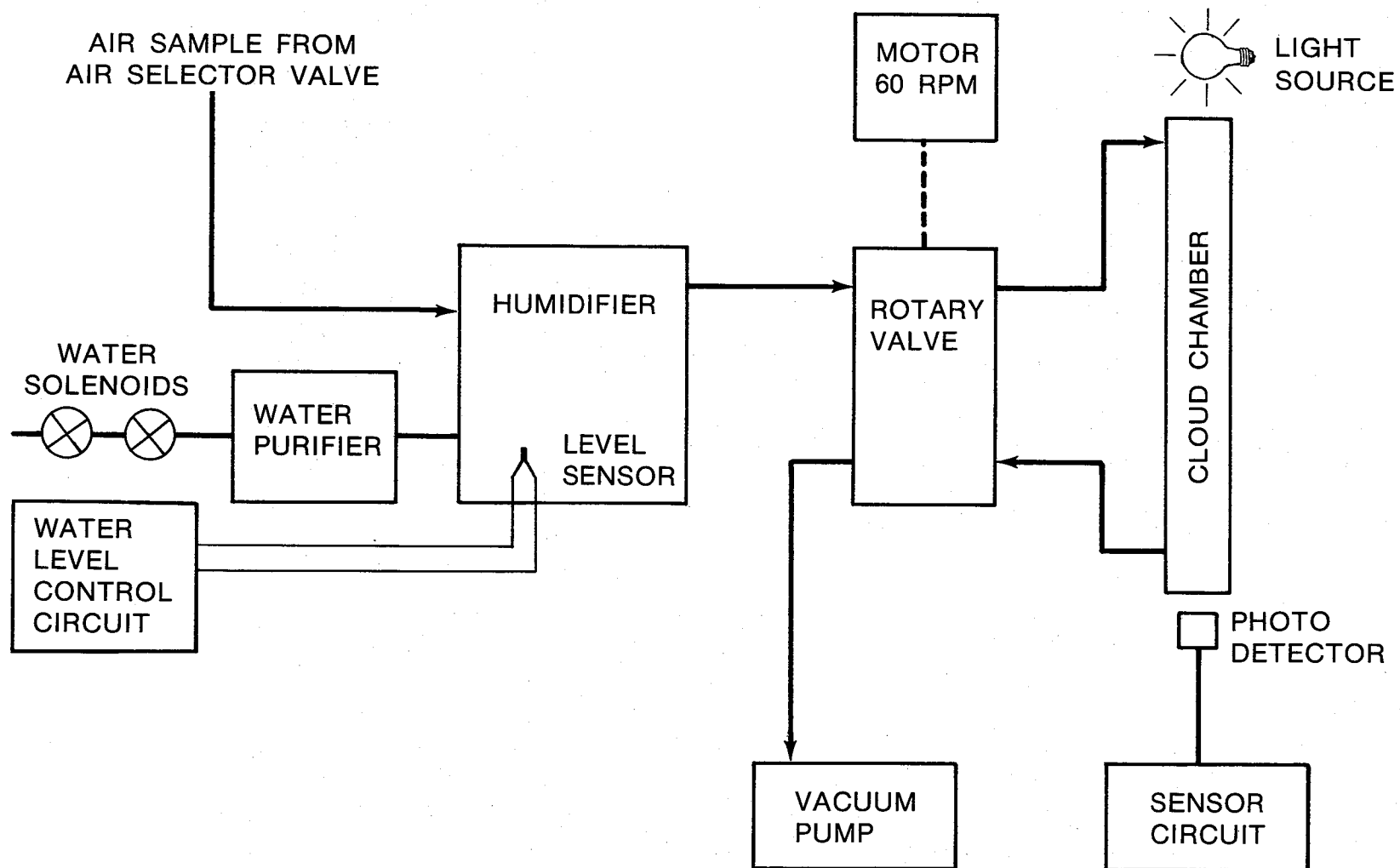


Figure 3. - Block diagram of measuring system.

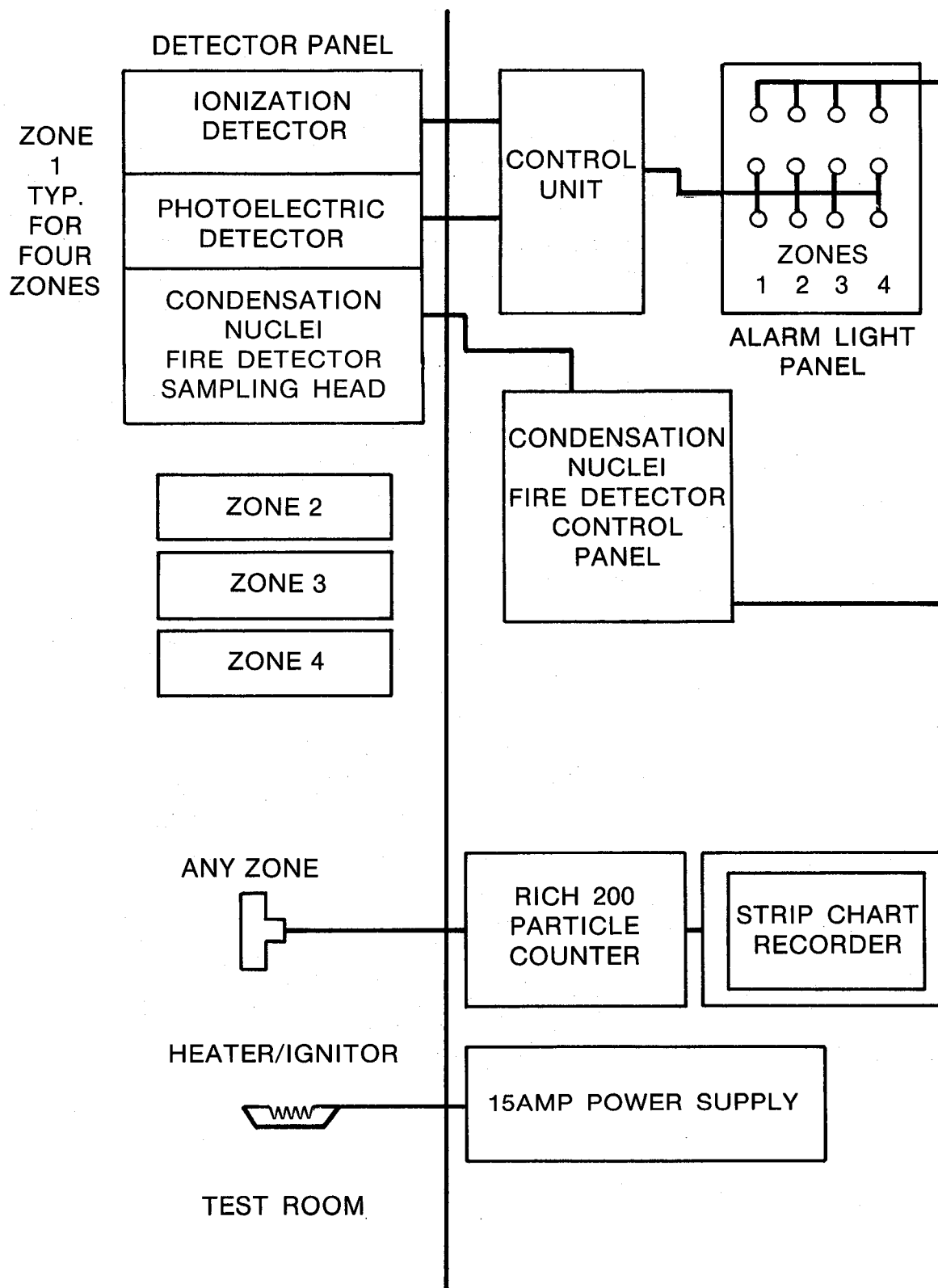


Figure 4. - Block diagram of detectors and sensing equipment.

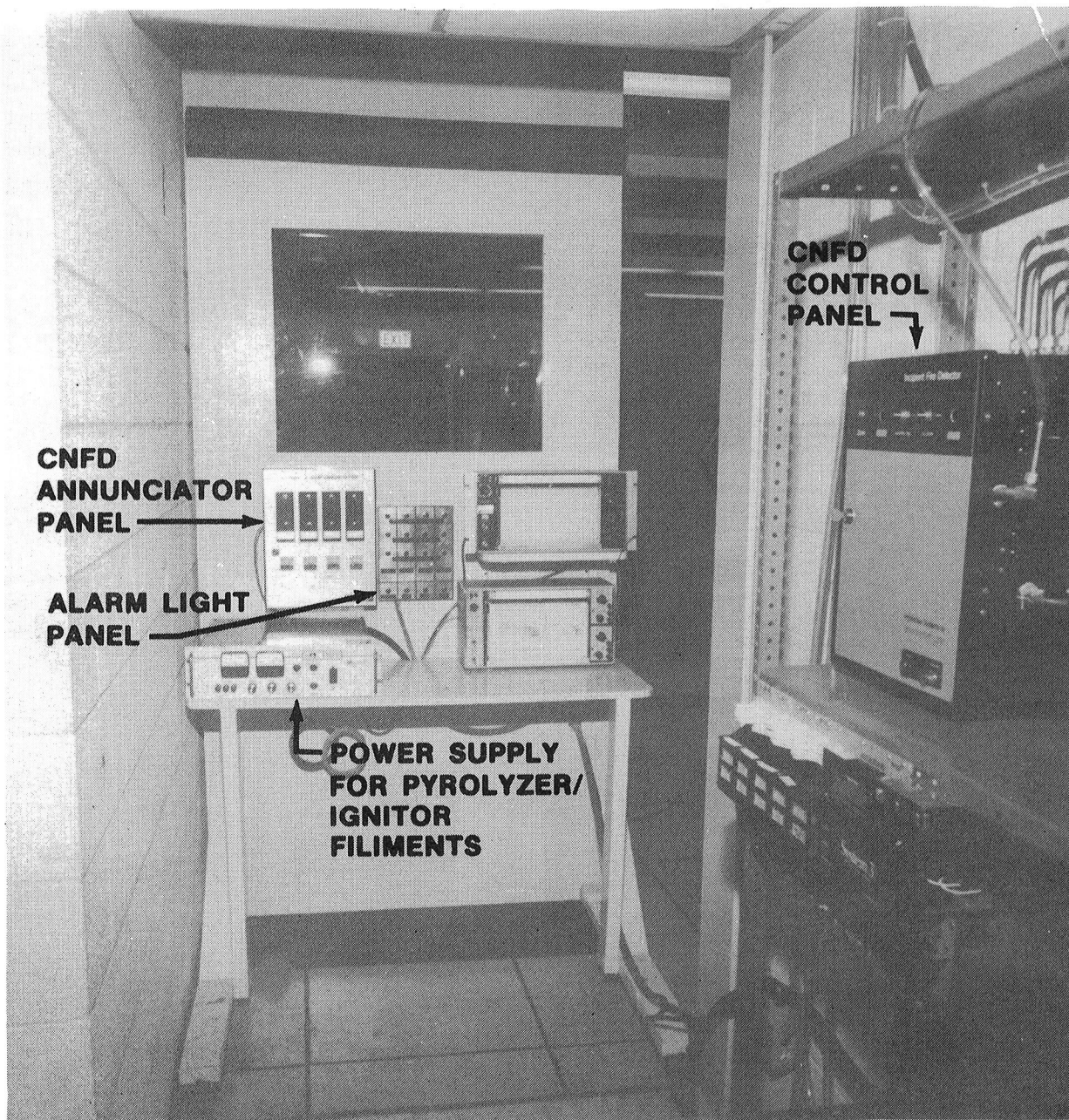


Figure 5. - Moveable control panel.

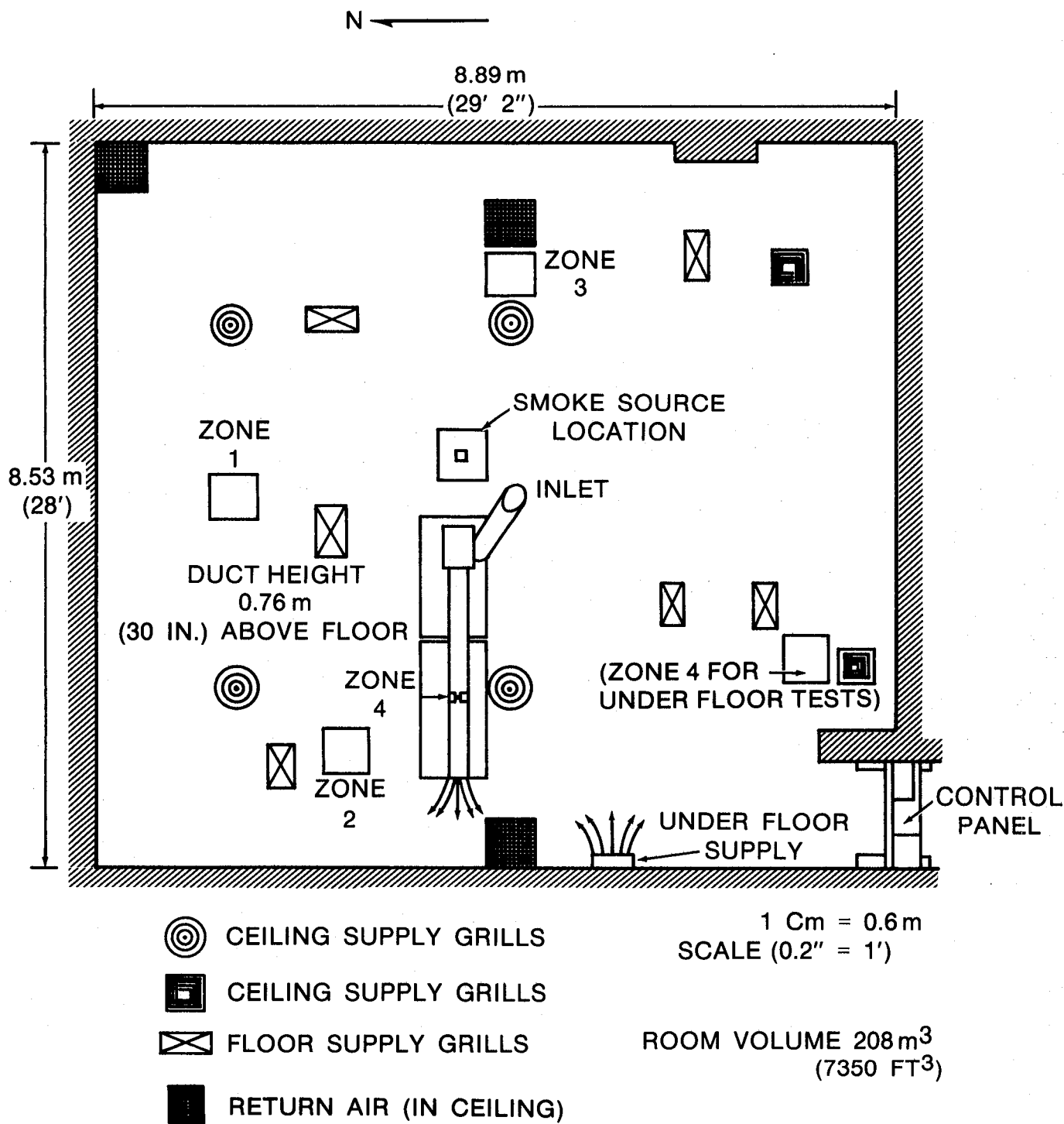


Figure 6. - Test room configuration.

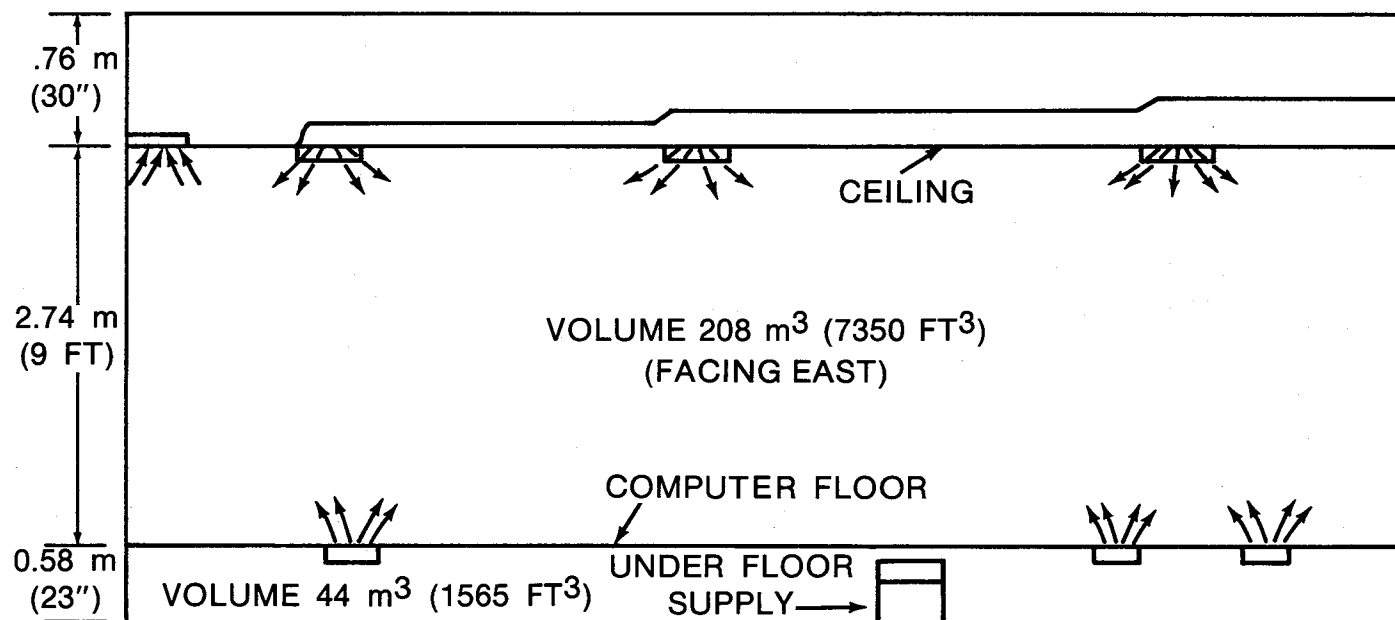


Figure 7. - Plan view of test room.

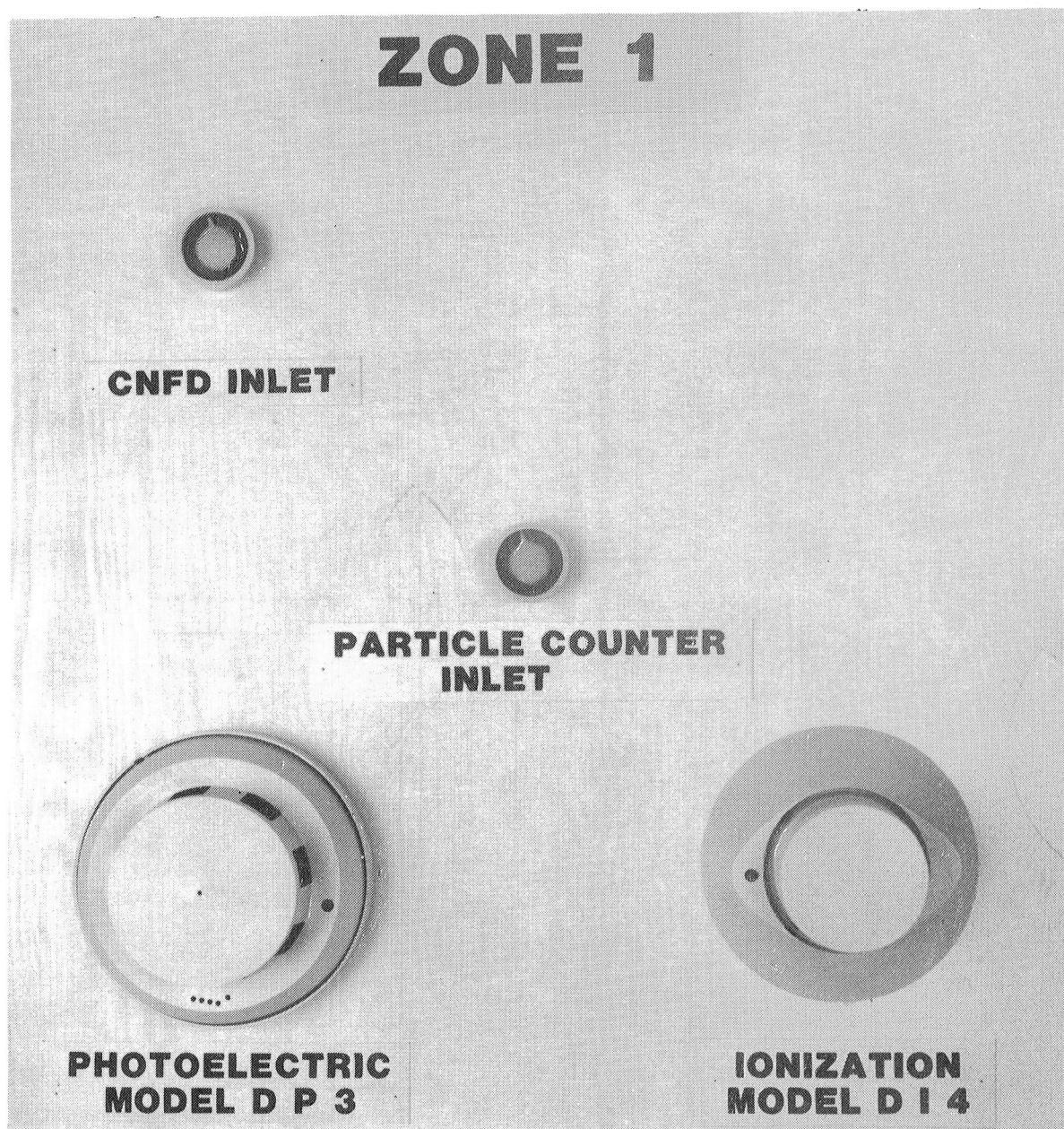


Figure 8. - Detector panel configuration.

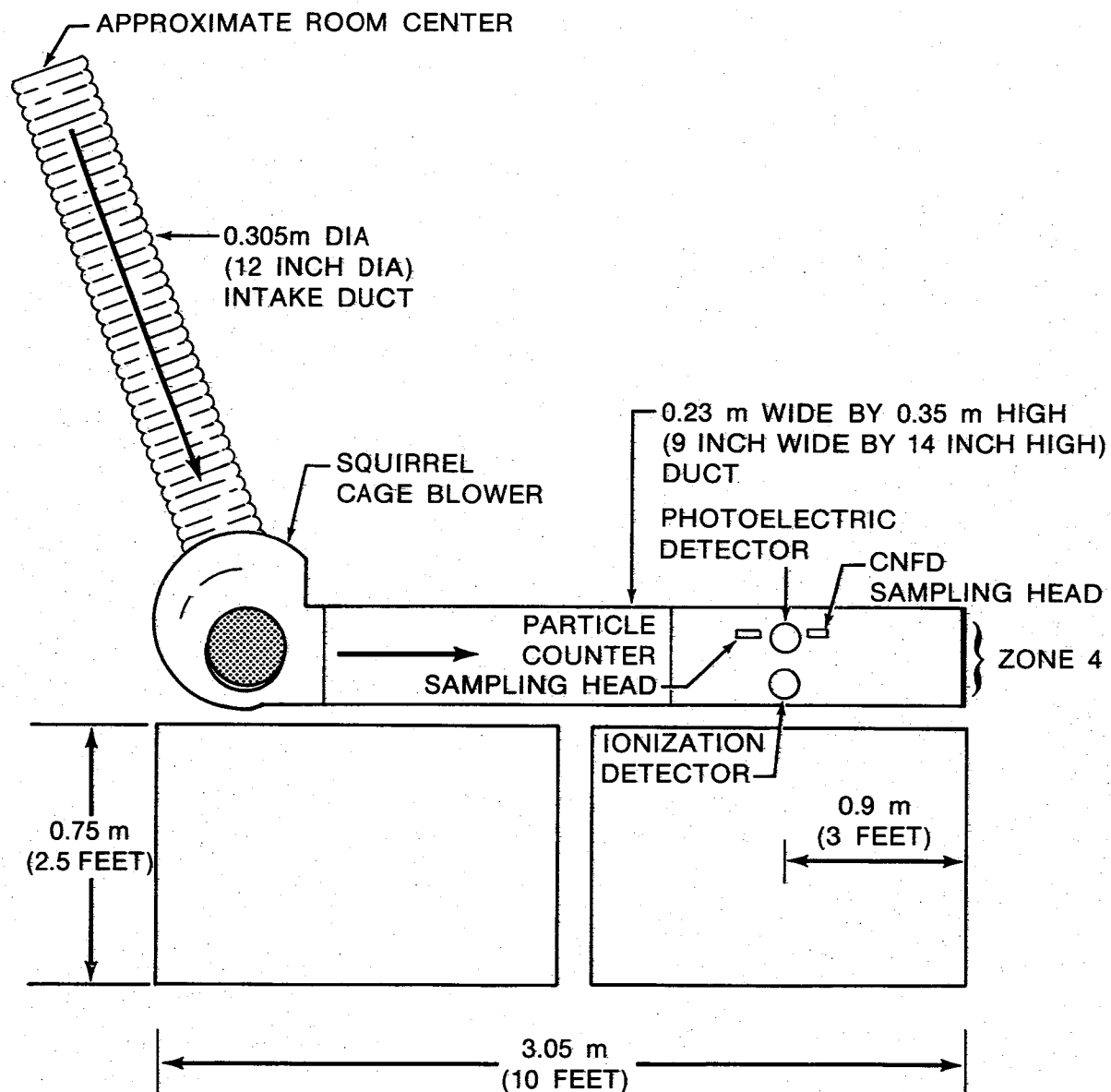


Figure 9. - Plan view of duct test setup.

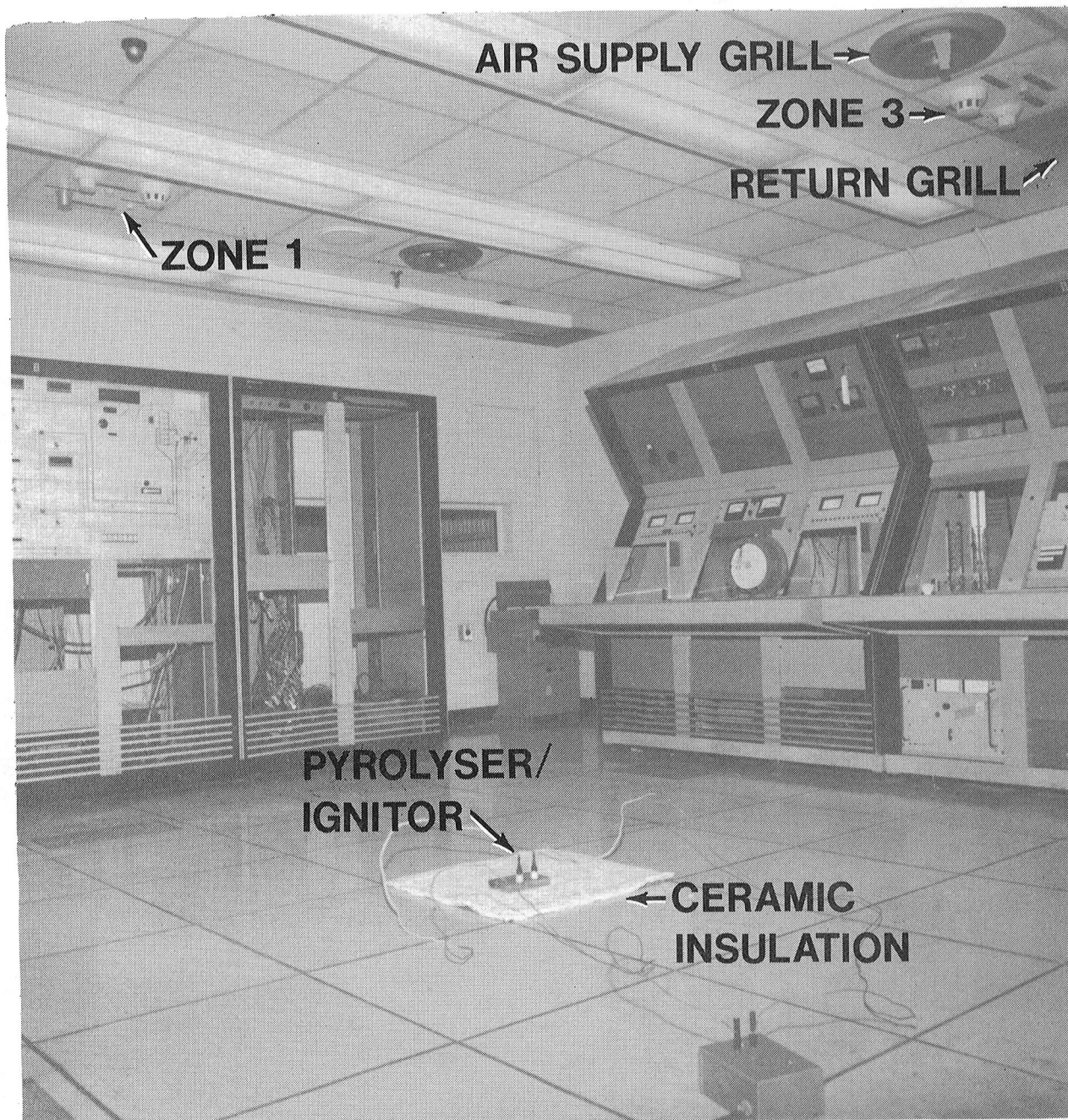


Figure 10. - Test room.

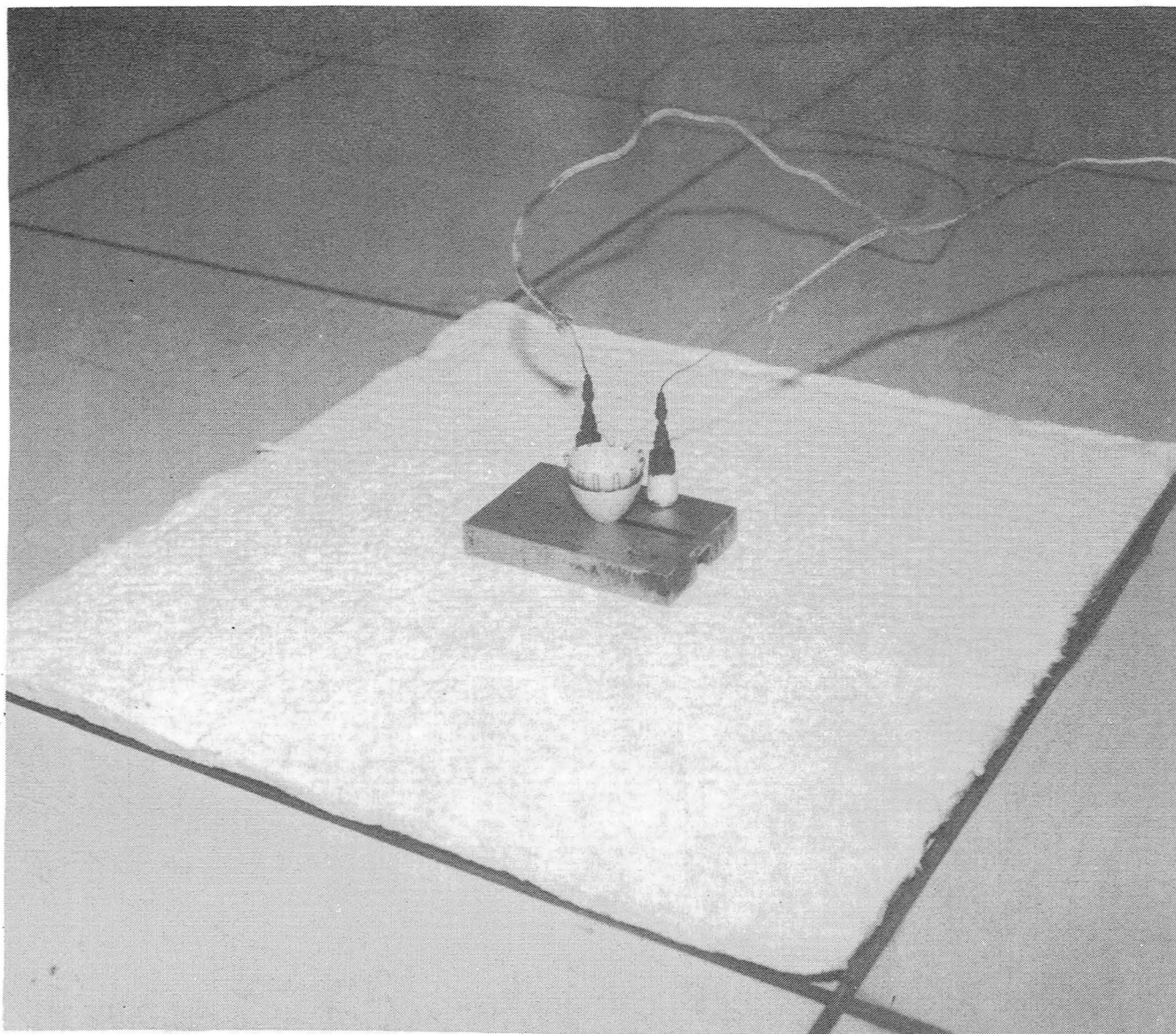


Figure 11. - Smoldering plastic heater.

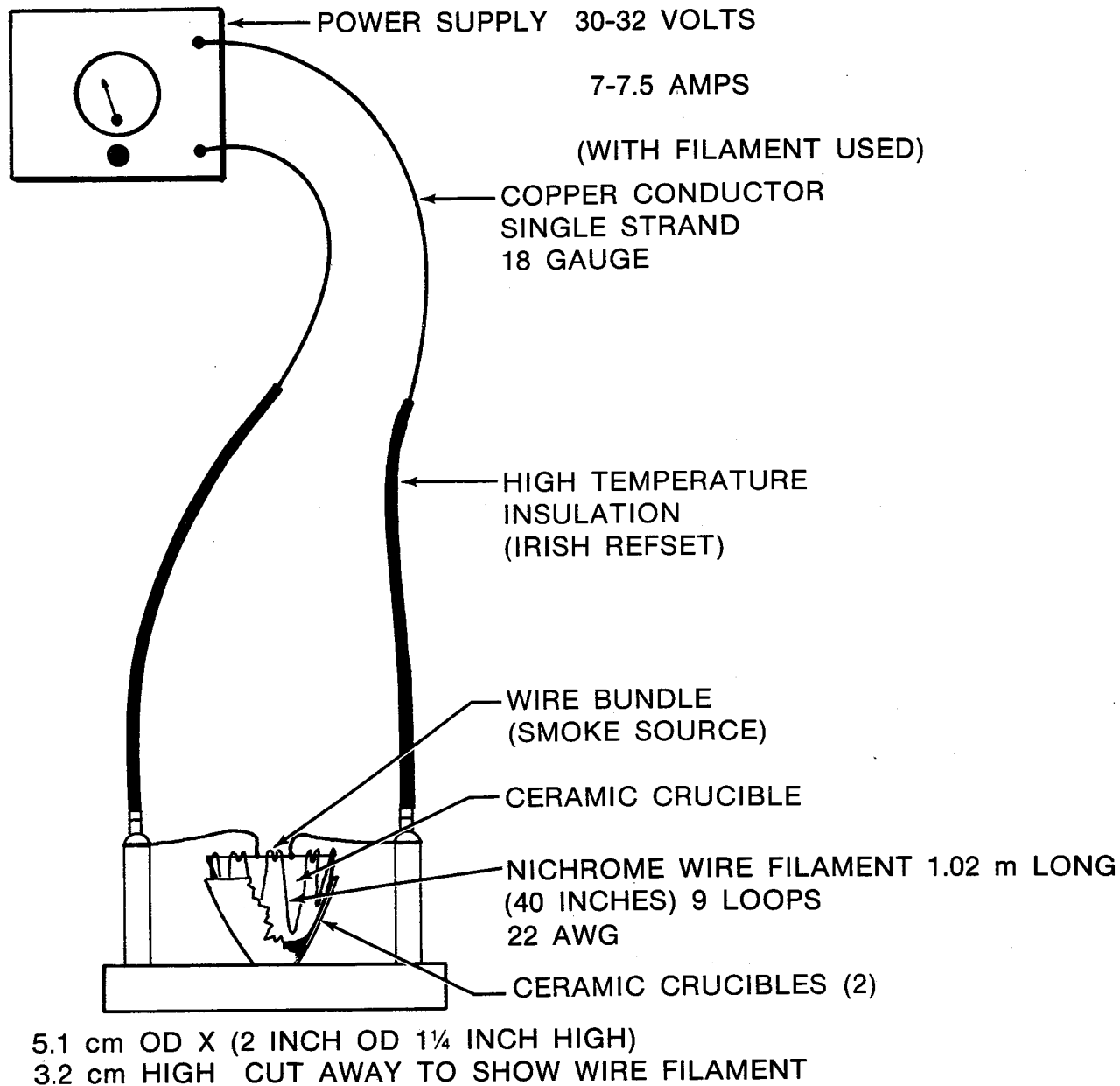


Figure 12. - Heater for plastic products of combustion (nonflaming).

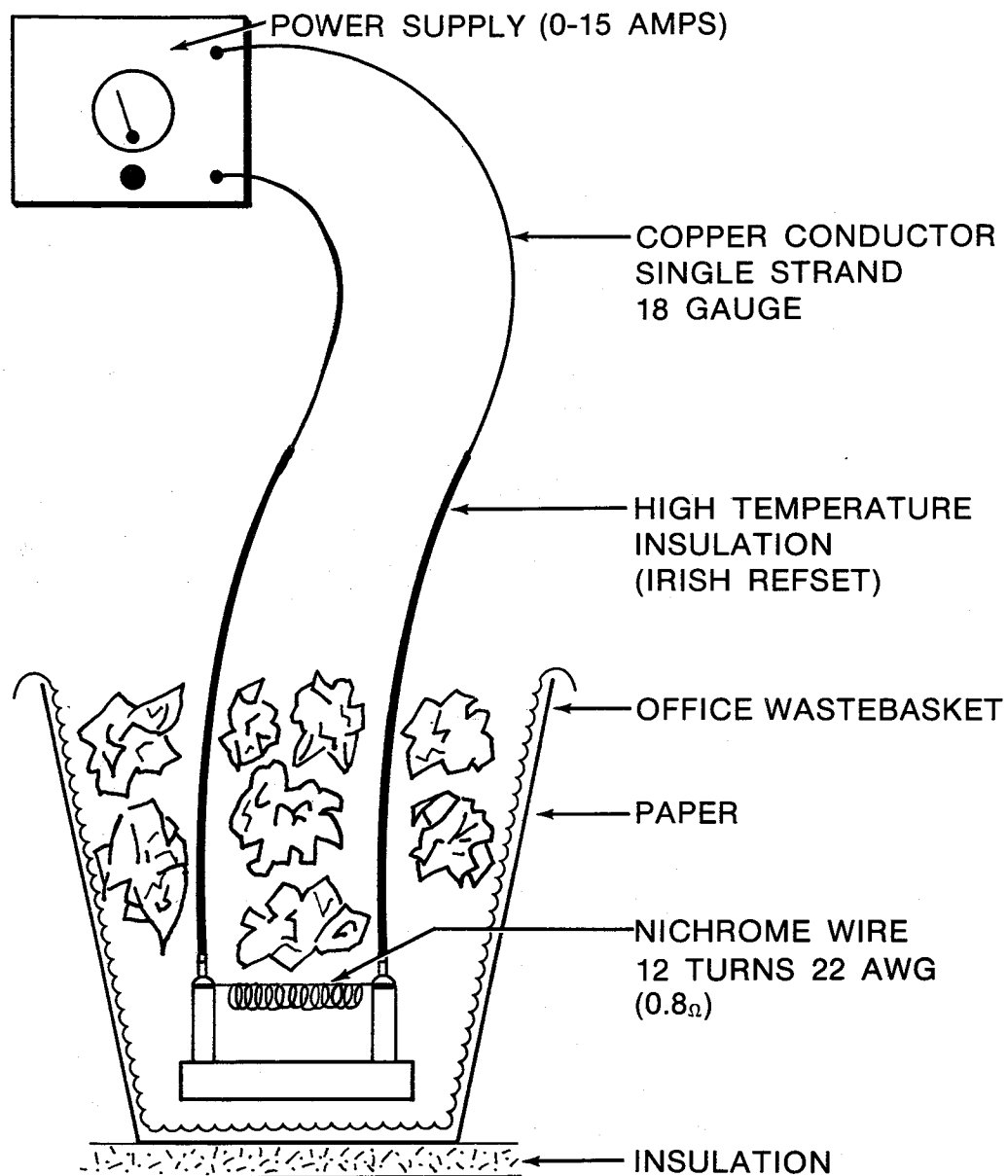


Figure 13. - Paper products of combustion test configuration.

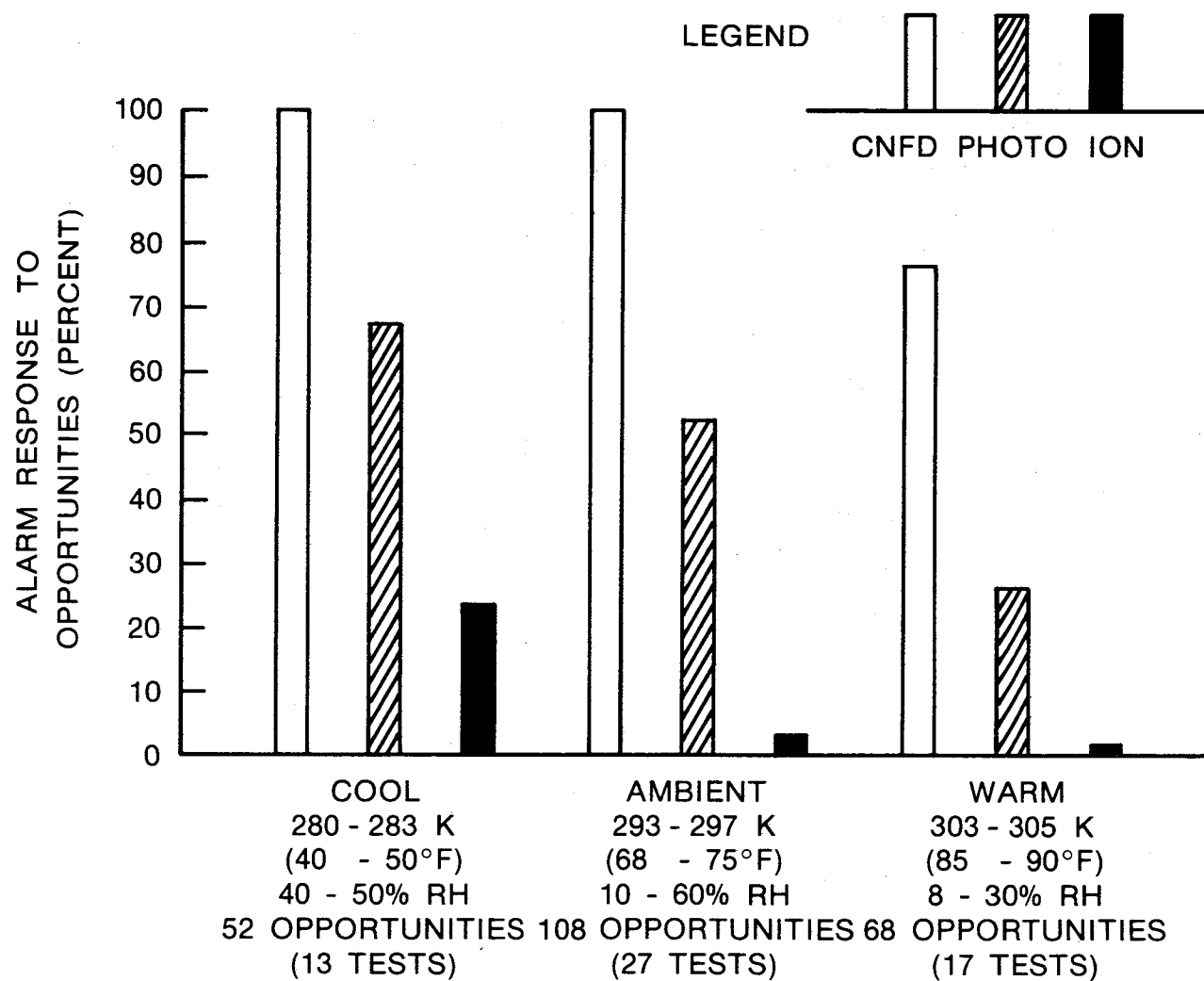


Figure 14. - Results for three environments with smoldering PVC.

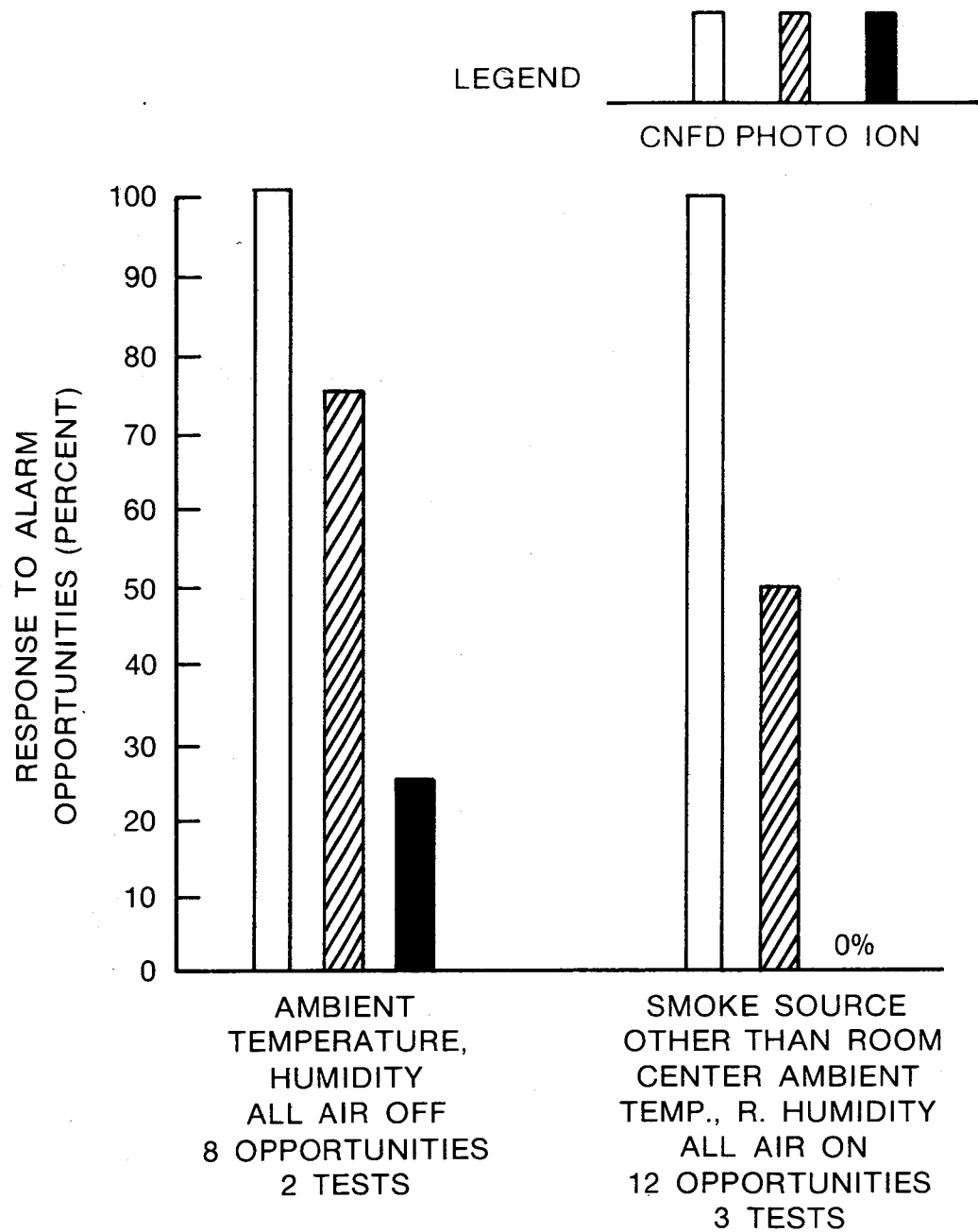


Figure 15. - Results with airflow off and relocating smoke source.

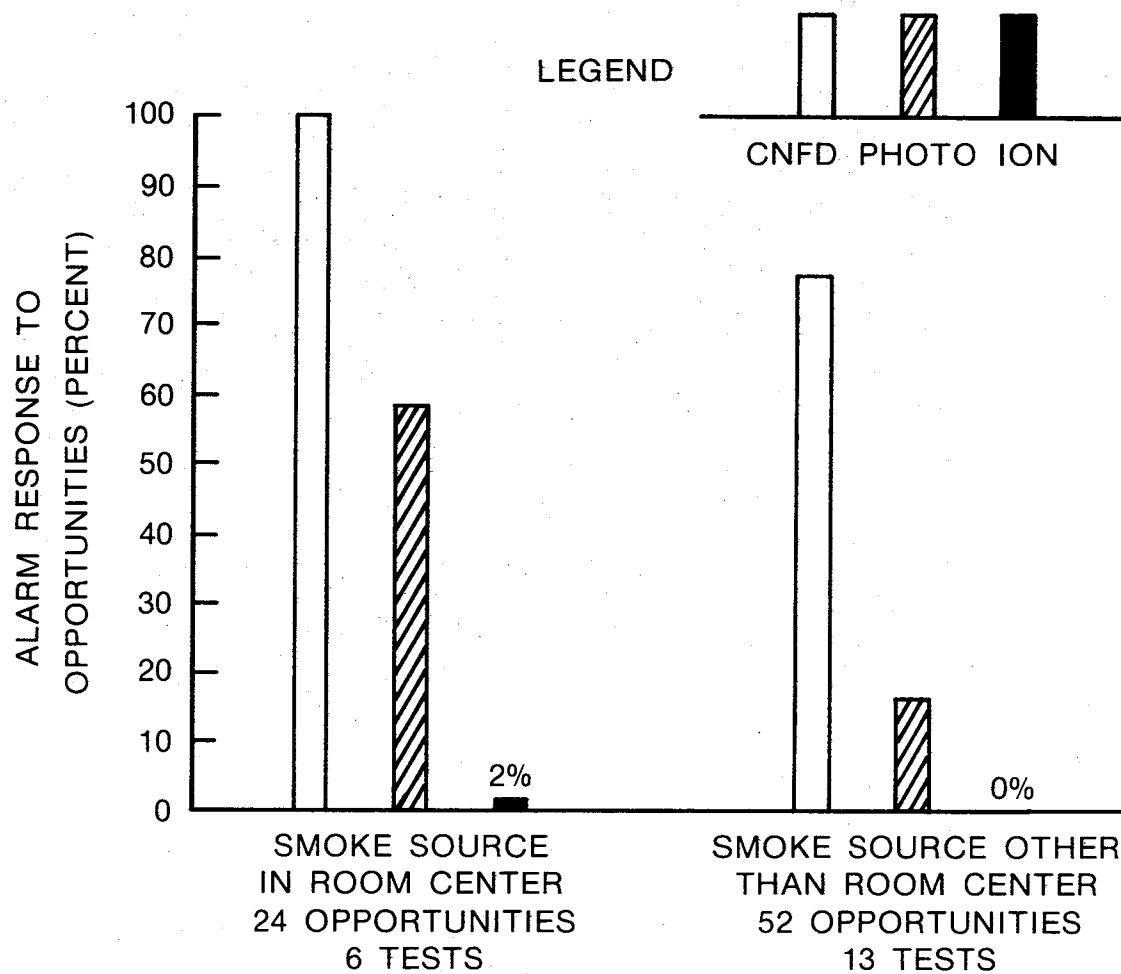


Figure 16. - Results of high airflow tests.

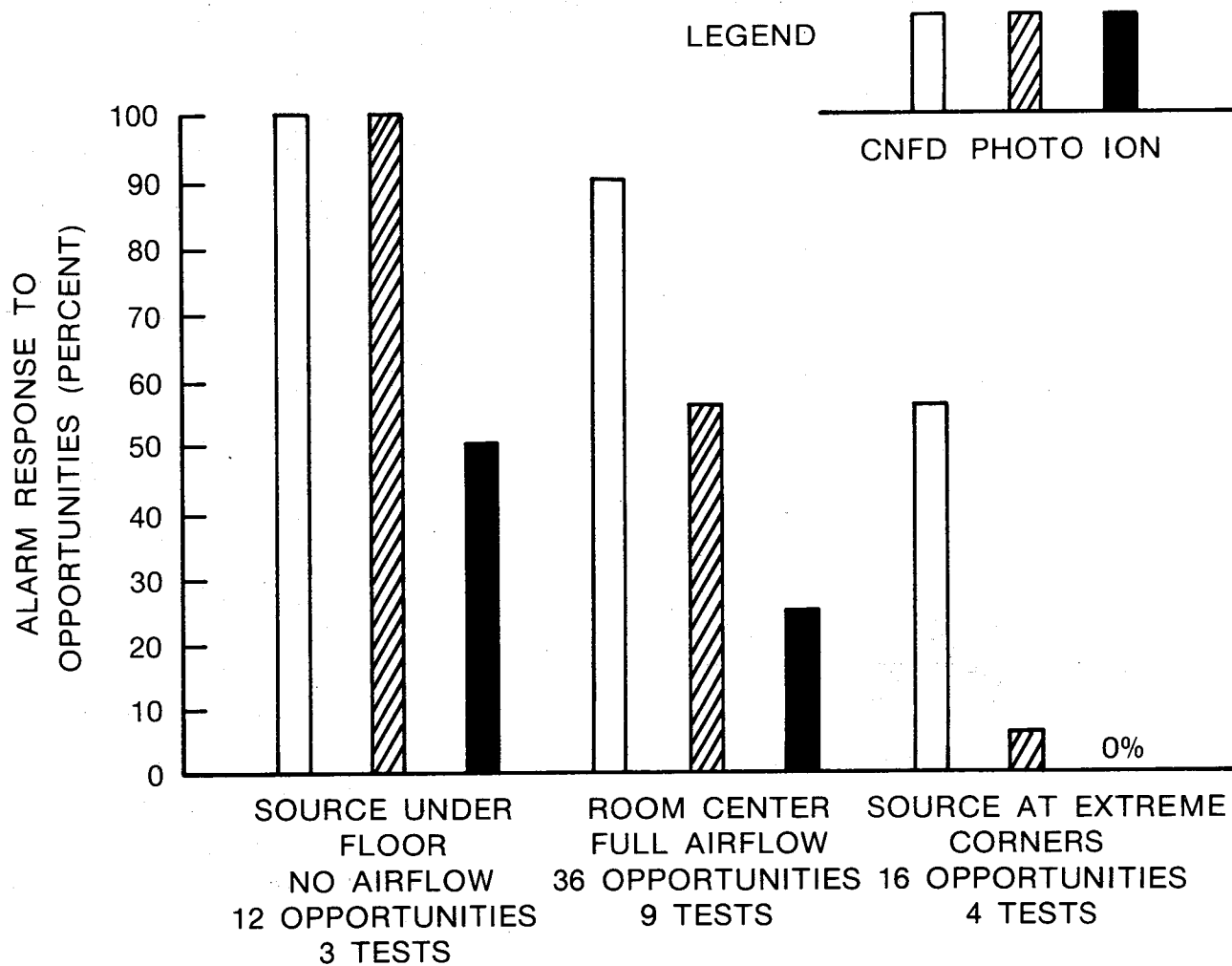


Figure 17. - Results of underfloor tests.

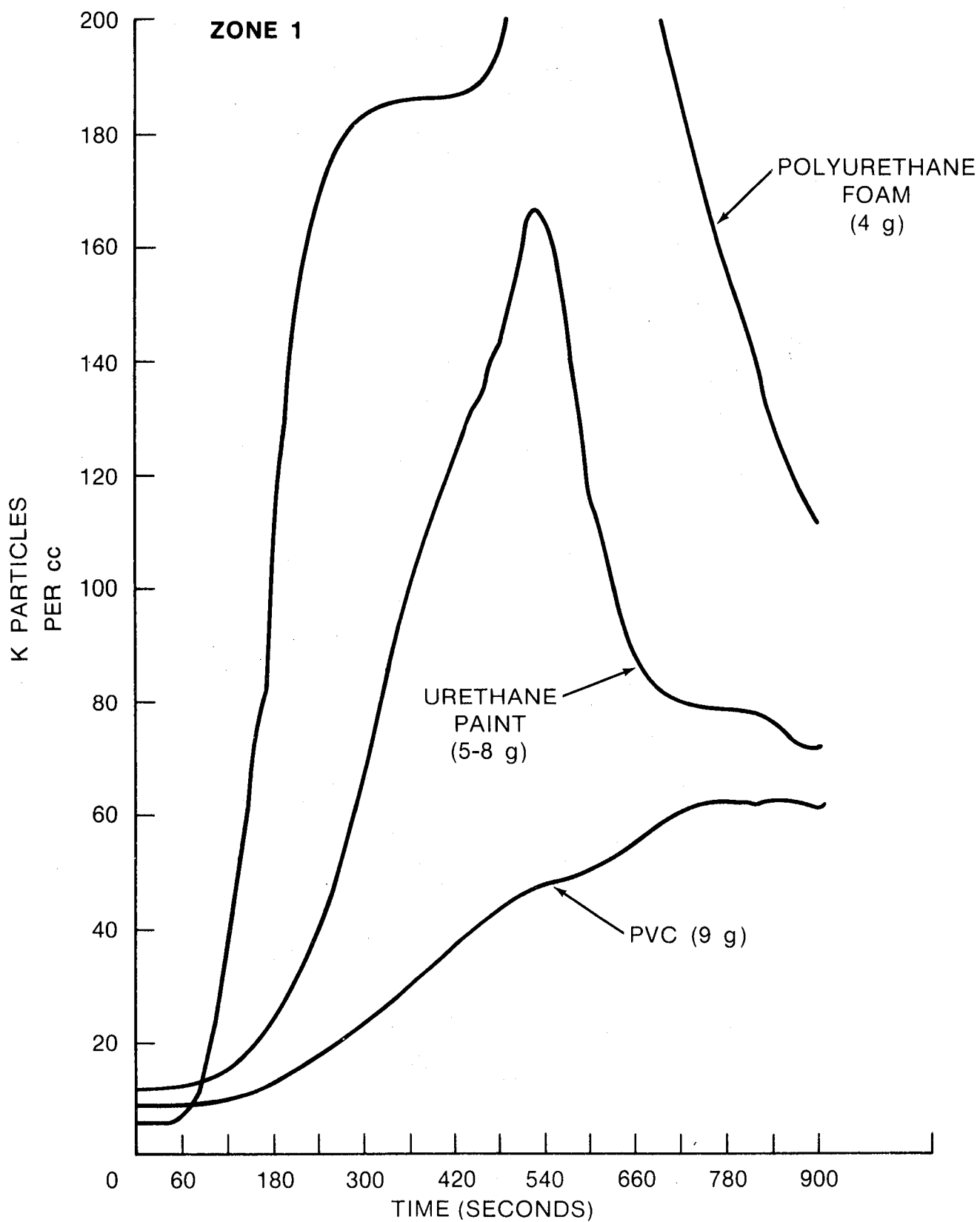


Figure 18. - Comparison of typical particle count from three plastic materials.

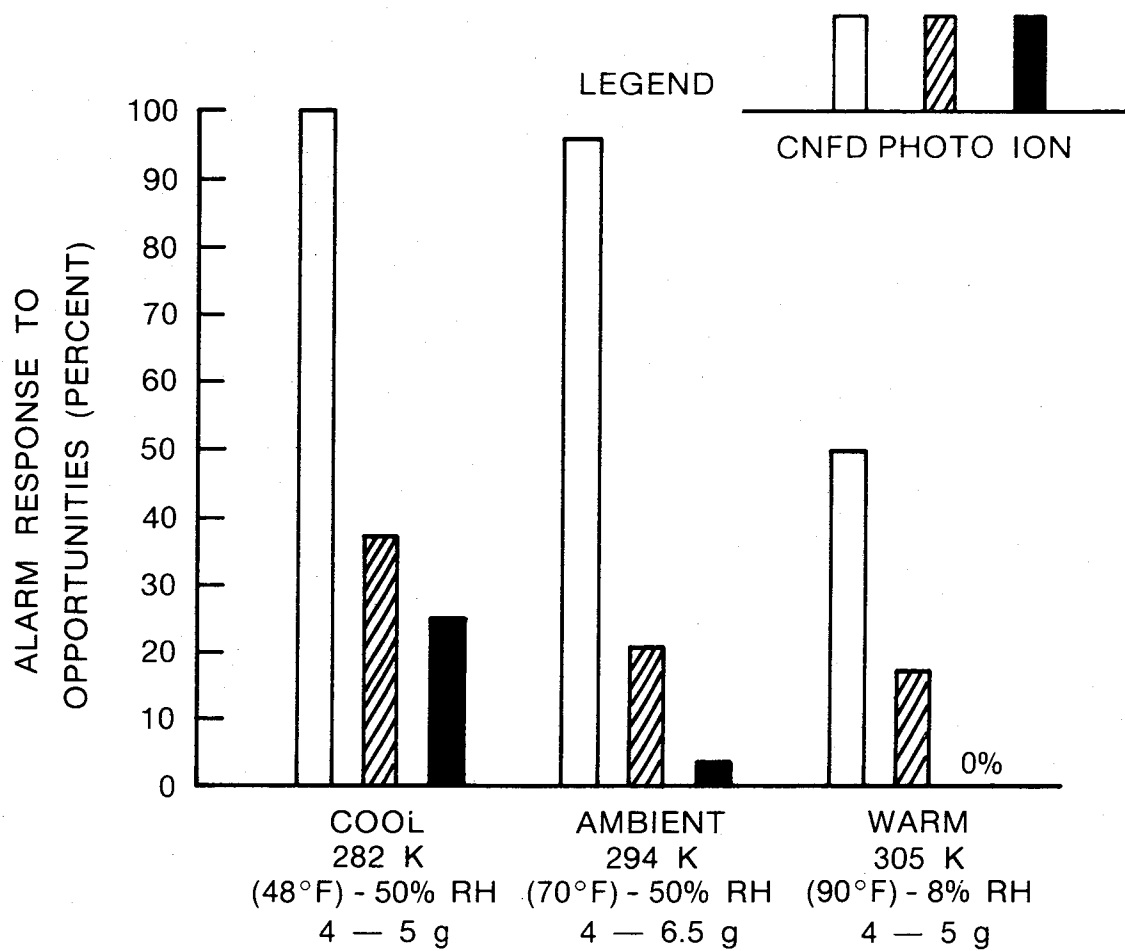


Figure 19. - Environmental effects on urethane tests.

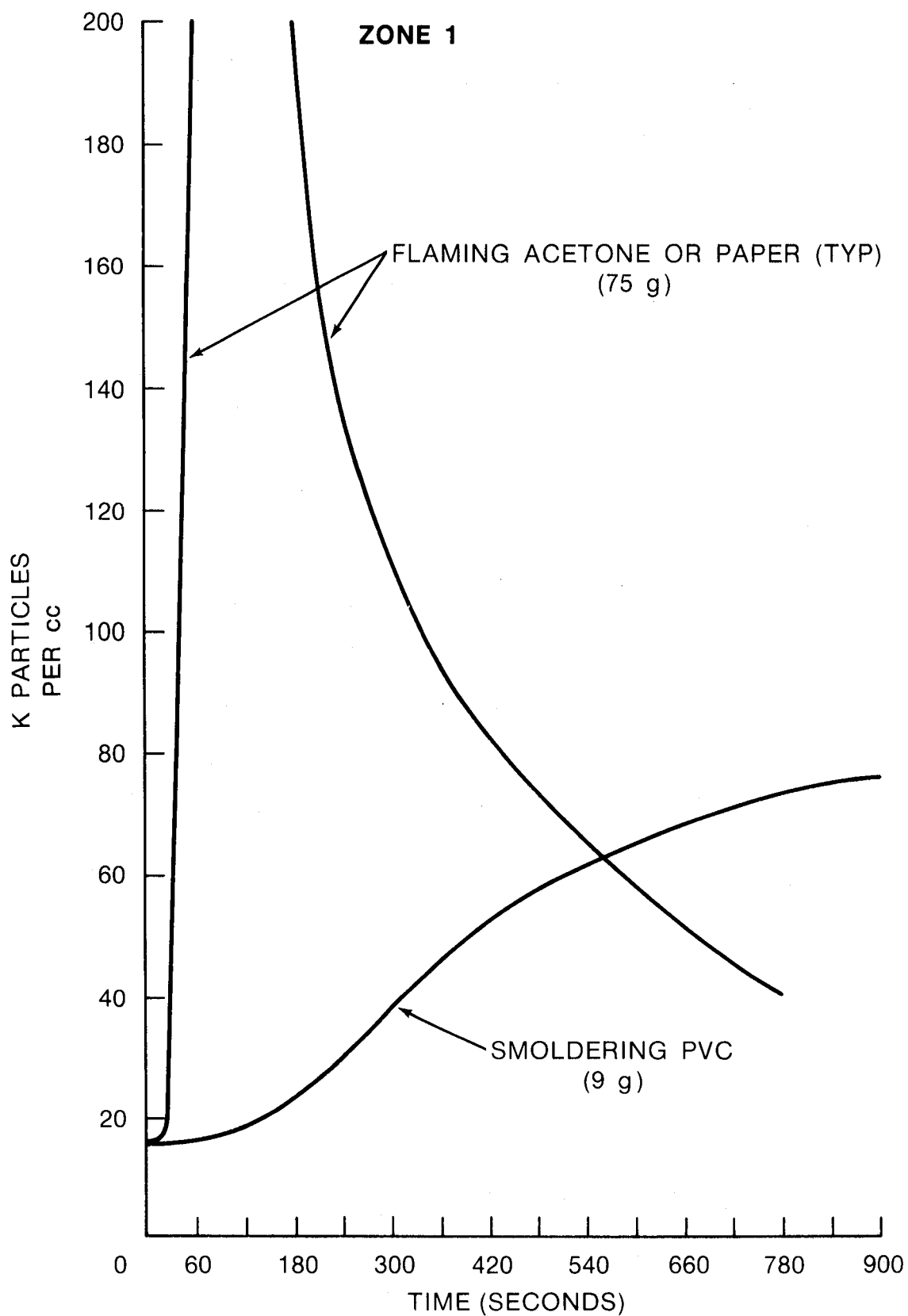


Figure 20. - Comparison of visible fire versus smoldering.

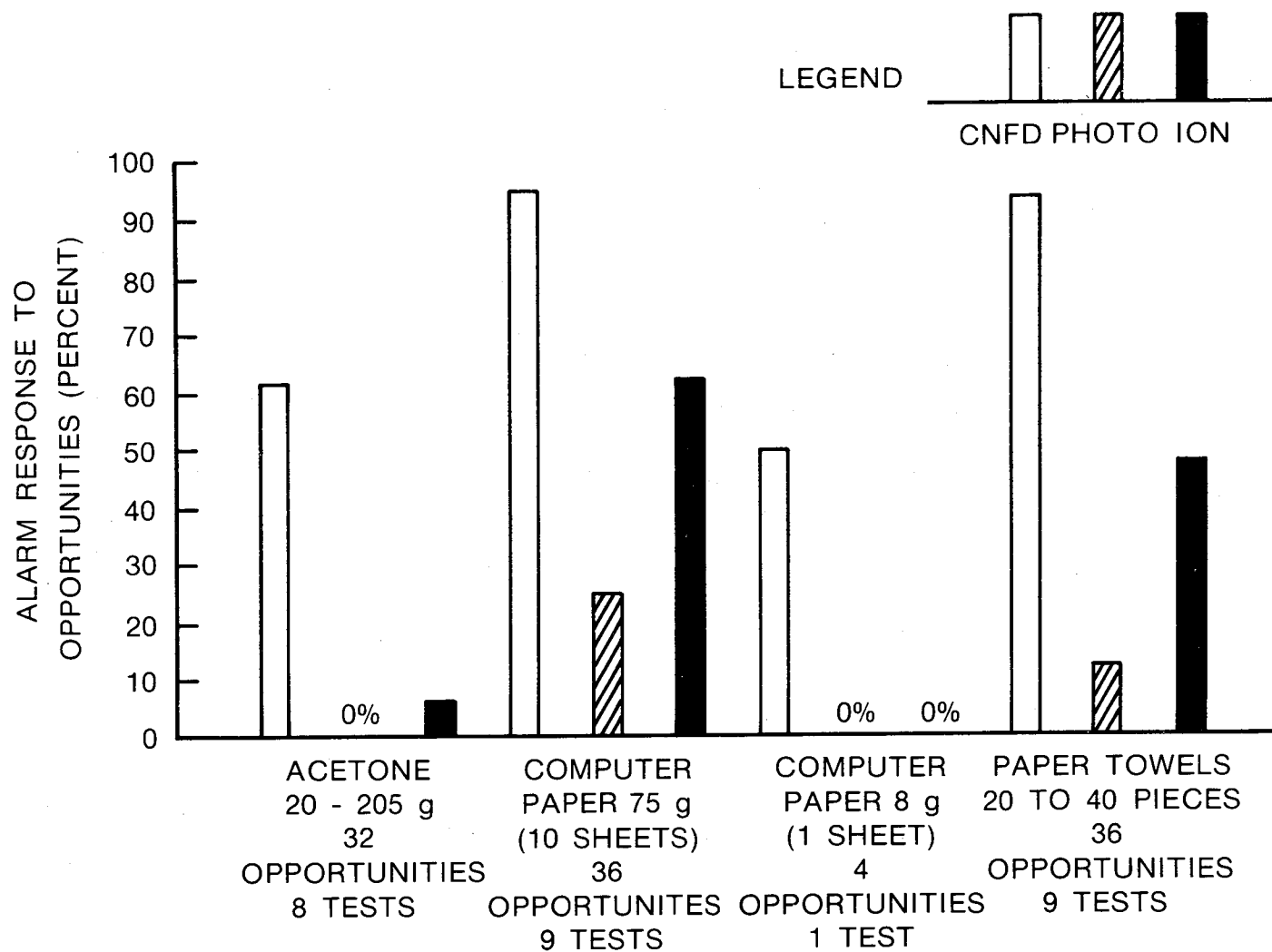


Figure 21. - Results for flaming combustion.

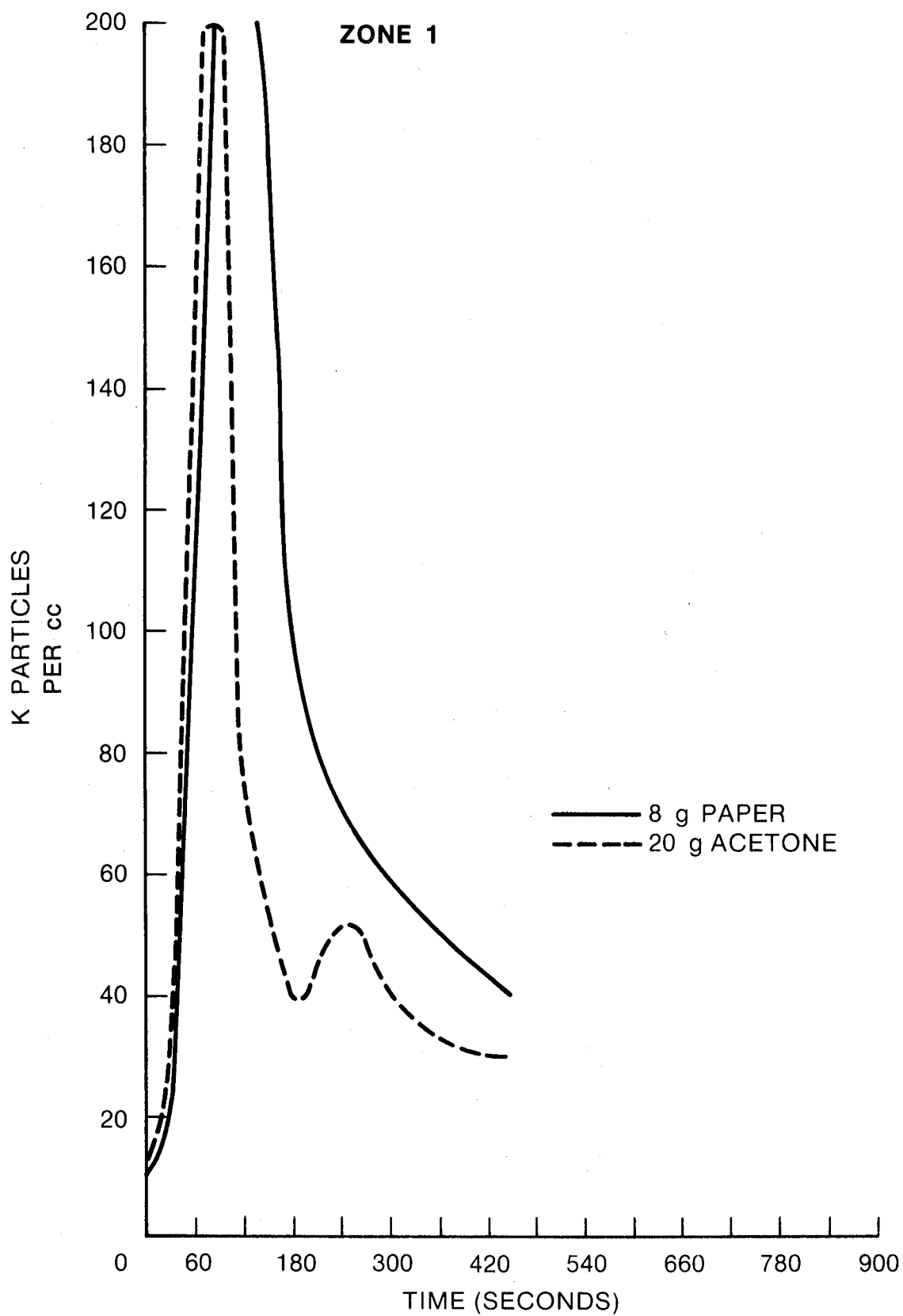


Figure 22. - Particle count for small quantities of paper and acetone.

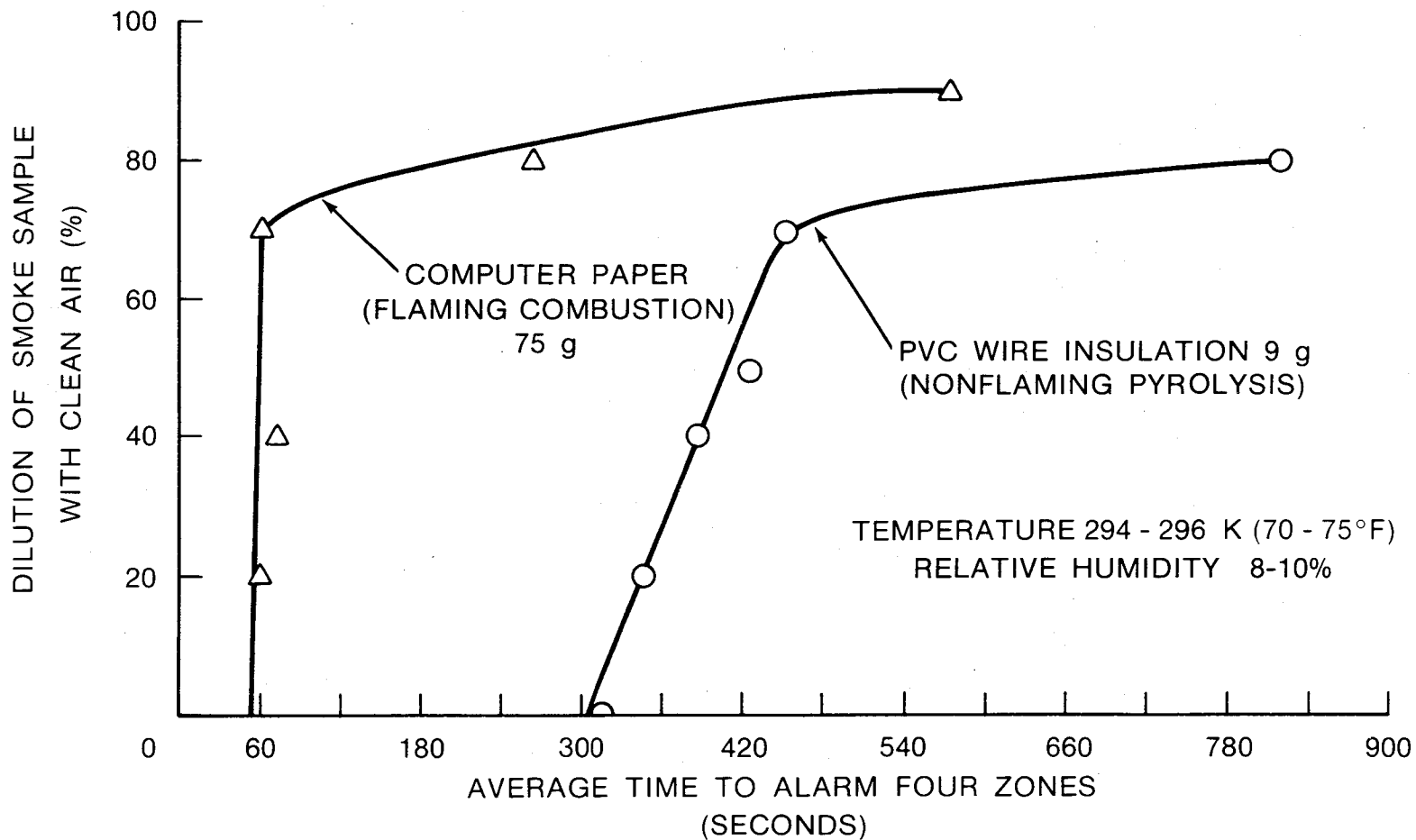


Figure 23. - Effect of sample dilution on average alarm time.

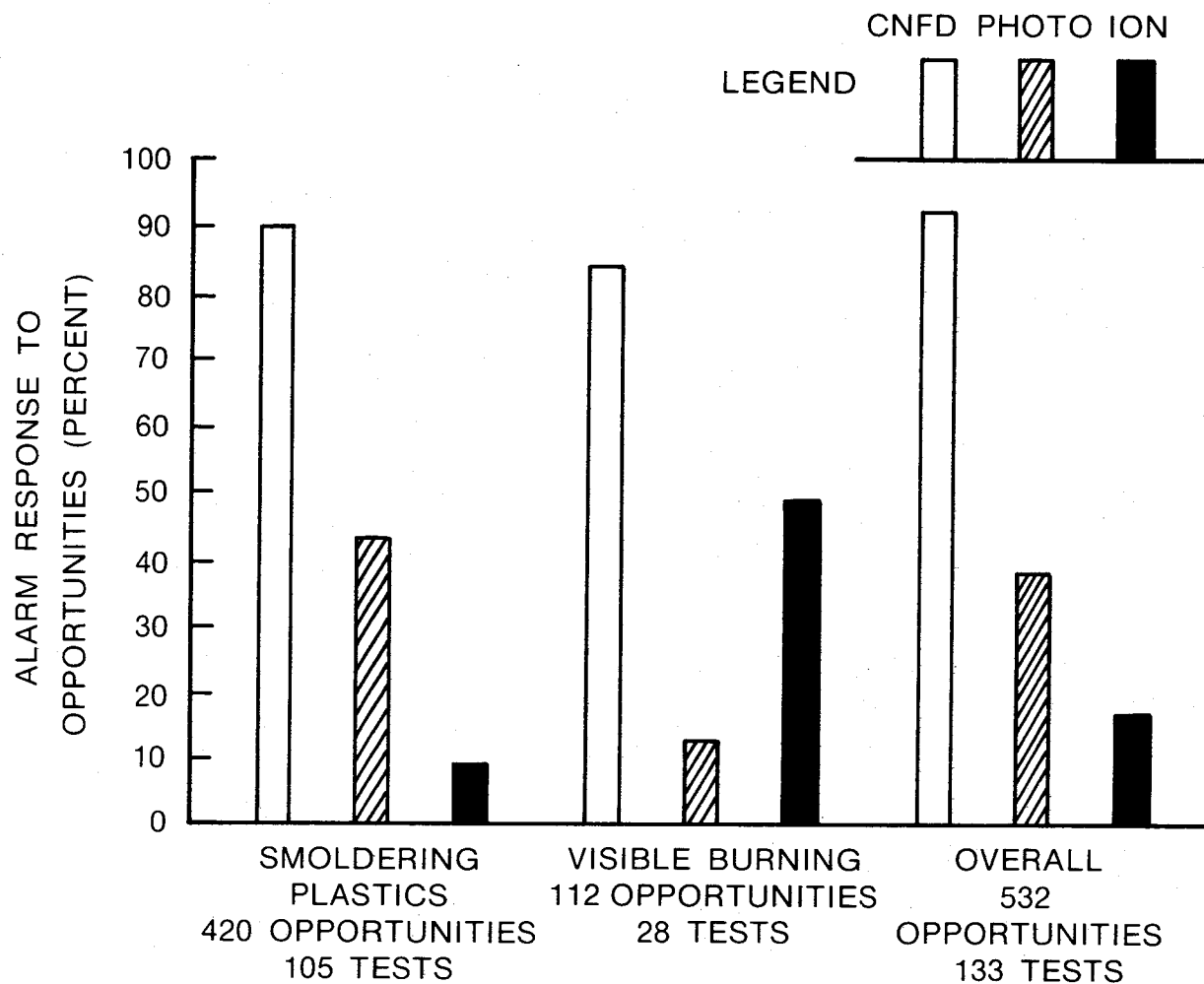


Figure 24. - Summary of results.

APPENDIX

INDUSTRY MAINTENANCE EXPERIENCE

This appendix contains a brief summary of experience with commercially installed CNFD units.

Webb, Murray & Associates, Inc., (W/M) has installed ten CNFDs in various clean room areas in the Dallas area. Since the maintenance experience with the test unit was not necessarily representative of a commercial installation, some of the problems encountered with these commercial installations are presented in the table. Several problems were found in the units prior to installation related to improper soldering, broken leads, and improper adjustment of vacuum level, which are indicative of insufficient quality control measures by the manufacturer prior to shipment. W/M has developed a preinstallation inspection and checkout procedure which is designed to eliminate these types of problems.

Many of the problems were associated with the malfunction light coming on. Part of this results from the extremely clean areas in which the units have been installed. W/M is reviewing ways that will eliminate this situation from causing the malfunction light to operate.

It is believed that with a more stringent preinstallation checkout and inspection and some minor modifications to the electrical circuitry, these unexpected problems with the CNFD will be eliminated.

WEBB, MURRAY & ASSOCIATES, INC.

MAINTENANCE EXPERIENCE FOR INSTALLED
CONDENSATION NUCLEI FIRE DETECTORS

| UNIT NUMBER | LOCATION | DATE | PROBLEM | WORK PERFORMED AND REMARKS |
|----------------|--|----------|-----------------------------|---|
| 1315 | Clean Room Sampling Heads in Intake to Air Circu- lation Blowers | 02/28/84 | Preinstallation Checkout | Added modifications per manufac- turer's recommendation. Replaced photocell. Broken lead. Resoldered capacitor on AC terminal strip. Replaced transistor in power supply - had fallen out. Leads too short to solder into board. |
| 1316 | Clean Room Sampling Heads in Intake to Air Circu- lation Blowers | 02/09/84 | Preinstallation Checkout | Added modifications per manufac- turer's recommendation. Replaced photocell. Voltage at terminals E & F very low. |
| | | 02/16/84 | Unit in Alarm | Unit had water in cloud chamber. Caused by turning unit on side while being checked out. |

| UNIT NUMBER | LOCATION | DATE | PROBLEM | WORK PERFORMED AND REMARKS |
|----------------|--|----------|-----------------------|--|
| 1291 | Clean Room Sampling Heads in Intake to Air Circu- lation Blowers | | History | <p>Unit installed early 1983. Ran without problems for 11 months. Went into malfunction. Unable to solve problem. Returned unit to Environment One for repairs.</p> <p>Manufacturer returned unit as repaired. Unit ran in shop 1 week. Reinstalled unit which ran for 1 week then went into malfunction. Cleaned cloud chamber. Rotary valve, unit set back up but would not hold sensitivity. Replaced with repaired unit.</p> |
| 1291 | Clean Room Sampling Heads in Intake to Air Circu- lation Blowers | 04/09/84 | Unit Missing Parts | <p>Brought this unit back to shop and used for spare parts as manufacturer is slow in shipping parts.</p> <p>Rebuilt unit with parts obtained from manufacturer. No photocell output. Replaced wire to photocell, still no output. Found voltage to sensitivity card low, wiring error on thermistor circuit corrected and unit working.</p> |

| UNIT NUMBER | LOCATION | DATE | PROBLEM | WORK PERFORMED AND REMARKS |
|----------------|--|----------|---|--|
| 1313 | Clean Room Sampling Heads in Intake to Air Circu- lation Blowers | 03/28/84 | Malfunction Light On | Checked voltages at power supply and sensor card. Adjusted particle generator - had no effect - removed unit for repair. |
| | | 04/01/84 | Malfunction Light On | Removed shelf unit. Cleaned rotary valve and cloud chamber. malfunction light still on. |
| | | 05/01/84 | Malfunction Light On | Readjusted vacuum pump from 7 to 9 inches of Hg. Malfunction light cleared. |
| 1301 | Clean Room Sampling Heads in Intake to Air Circu- lation Blowers | 03/28/84 | | Installation |
| | | 04/27/84 | Malfunction Light - Low Sensitivity | Variable resistor for particle generator voltage adjust open. Replaced same with new rheostat adjusted for proper voltage. Unit set up correctly. Once every cycle, unit would spike up into alarm area. Removed unit for repair. |
| | | 05/01/84 | Malfunction Light | Light Emitting Diode (LED) lead broken - must replace LED before any further checks can be done. |

| UNIT NUMBER | LOCATION | DATE | PROBLEM | WORK PERFORMED AND REMARKS |
|----------------|--------------------------------|----------|---------------------|--|
| 0093 | Various (demon- strator) | 04/12/84 | Repair as Needed | Replaced photocell and cleaned cloud chamber, rotary valve. Checked all voltages. Rotary valve motor bad. Replaced same, unit ran for 3 days then blew fuse. Rotary valve stuck again. Replaced humidifier block, cloud chamber, and rotary valve. |

| | | | |
|---|--|---|------------------|
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| 4. Title and Subtitle Test Results From a Comparative Evaluation of a Condensation Nuclei Fire Detector | | 5. Report Date March 1985 | |
| | | 6. Performing Organization Code | |
| 7. Author(s) Richard W. Bricker | | 8. Performing Organization Report No. S-543 | |
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| 16. Abstract A series of 138 tests was conducted to compare the fire/smoke alarm response of a Condensation Nuclei Fire Detector (CNFD) with photoelectric and ionization detectors. Tests were conducted in a former control room 8.5 m (28 ft) by 8.9 m (29 ft 2 in) with a 2.7 m (9 ft) ceiling. The room had air supplied from above the ceiling and under the floor with return air exiting from ceiling grills. The environment was varied from 278 to 305 K (40 to 90 °F) and relative humidities from 8 to 65 percent. Four detection zones were located in the room. Each zone contained a sampling head for the CNFD, a photodetector, and an ionization detector so that each detector system had four opportunities to alarm during tests. The particle level in the test room was also monitored during tests with a condensation nuclei particle counter. The CNFD responded to 90 percent of exposures to smoldering plastic and 84 percent of exposures to visible fire. The photoelectric response was 43 and 12.5 percent respectively for the same conditions. The ionization response was 9 and 48 percent respectively. | | | |
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